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THE GLAZER'S BOOK

And How to Use It.

By E. L. RAES.

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CHAPTER I.

GLAZER'S SECRETS AND RECIPES.

There are few things in a pottery or glazed brick factory on which the ambitious employees cast more longing glances than they do at that wonderful collection of recipes which the head glazer has collected in his "book," and there are few men who can resist the temptation to obtain possession of some of the information contained therein by either fair means or foul.

Although the majority of glazers and other people connected with the manufacture of glazed goods imagine that there is a great deal of mystery about the recipes used by the makers of glazes, this idea is almost entirely the result of a persistent effort on the part of the glaze mixers themselves to cast an air of mystery and secrecy over their operations, because they fear that they would have to work for much smaller wages than at present if their employers possessed the information they so assiduously attempt to keep to themselves.

There is, however, but little need for anxiety in this direction as there are many matters in connection with glazing which can only be gained by practice, and a skilful glazer can always earn a good wage. In those few cases where a glazer receives an unusually high wage there is less reason for surprise that the recipes contained in his book should be guarded with the most jealous care, and all those who attempt to increase the spread of knowledge of composition of glazes should be regarded with suspicion and dislike.

In bygone days the "secrets" of many trades were similarly guarded, but with the progress of science one trade after another has had its hidden

treasures discovered, and the so-called secrets have been found to be the common property of most of those who worked in the trade. The result of this spread of information, instead of ruining the trades concerned, as was expected, has led to a considerable increase in the business done, and the encouragement given by the trade journals for the publication of new recipes and improved methods of working has resulted in a great advantage to workers and users alike.

One of the results of the great secrecy maintained by glazers as to the compositions of the mixtures used by them has been the sale at enormous prices of books of recipes, or even of single recipes. In most cases the purchaser of these has found to his cost that he could not obtain the results he desired, and has (in his mind at any rate) accused the seller of fraud.

Fraud is by no means always intended, though in some instances it is difficult to avoid reaching this conclusion. The probability in most cases is that a glaze which is admirably suited for one clay and under certain conditions of firing may be entirely useless for another clay fired under different circumstances. As the purchaser and seller of these recipes are usually both quite destitute of any knowledge of the composition and properties of the clays, and the effects these have on the glaze, it is not surprising that disappointment is frequently felt when a recipe has been obtained at a considerable expense, and has been found to be quite useless for the purpose for which it was obtained.

As a rule, the most valuable recipes are those for use on fired or biscuit goods, because these change but little, if at all, in the firing, and enable one glaze to be used with a much greater variety of materials than when it has to be applied to the unfired or green ware. Indeed, recipes for glazing green bricks and tiles are almost valueless unless the fullest particulars of the clay are known, and they can only have a notable financial value in

the hands of those who consciously or unconsciously mislead prospective buyers into the belief that they have an almost priceless secret to dispose of.

That this condemnation of the ordinary value set upon recipes by those possessing them is not expressed in exaggerated terms can easily be proved by asking a man with such a recipe to sell to go to a certain works, and there put his knowledge to the test of practical work. In not one case in a score will he be able to use his recipe without some alteration, larger or smaller, according to the difference in the properties of the new material on which he must work, and it is precisely in the ability to make these alterations with the smallest loss of time that the skill of the true glazer lies.

Another fallacy which has been the ruin of not a few men is the belief that a glaze is suitable for all clays which can be fired at a given temperature, and which have about the same contraction or shrinkage. As a result of this belief many men have taken contracts or signed agreements for a fresh situation where the clay is similar to that on which the glaze has been successfully worked by them for a considerable number of years. They have obtained the ingredients of the glaze from the same firm, have fired the goods under apparently identical conditions, but have discovered too late that some slight difference in the clay (they do not know of what kind) has prevented the glaze from being used to the satisfaction of their new employer, and so they have lost what might have been a good situation had they only known how to adapt the glaze to their new clay.

It must never be forgotten that a glaze which may be admirable for a certain clay, and under certain conditions of working, may be entirely unsuited to other similar clays in a different part of the country, and many a man who has stolen or bought recipes has found to his cost that they have been of little or no use to him.

The fact is that glazing bricks and tiles is not unlike cooking cakes and puddings; a good workman can make his own recipes if he understands his work properly, whilst a poor hand will only make a mess of things, even though he be supplied with the fullest particulars and recipes. Consequently, whilst these recipes have a value of their own, it is not nearly so high as most people appear to suppose.

It is the purpose of this book to show some of the weaknesses and defects of the glazer's book as commonly understood, and to indicate some means of remedying them. At the same time, it is not intended to prejudice the interests of any who are earning their living by the production of glazes, but simply to refer to certain types of glaze and "body" which are already public property, with a view of showing how they may be modified and varied to suit the varying needs of different works and conditions. At the same time, it must be distinctly understood that the application of glaze to clay is a matter requiring the utmost care and skill, both in the manufacture of the ingredients, the mixing of the materials in the right proportions, and in applying them in the proper manner to the clay or biscuit ware. Hence it is unlikely that such problems as the production of a new glaze to a known clay, or the alteration of an old glaze to new clays, can be solved without the aid of considerable scientific knowledge, except by the long, wearisome and disappointing method of "trial and error," in which the experimentor tries a number of mixtures which occur to him as being suitable, and then alters them in any way he thinks fit, until—more as the result of chance than of knowledge—he at last obtains a mixture which satisfies him.

Many men have spent the whole of their lives and large sums of money in the attempt to prepare glazes to fit certain clays, but have failed to obtain them because they did not know sufficient of the properties of the materials they used to enable them to know in what way the alterations should be

effected in order to correct this or that defect, or to increase or reduce the temperature at which the glaze melted.

The case of Bernard Palissy, the first man who, in modern times, discovered the method of glazing earthenware, is well known on account of the hardships he had to suffer, and the privations endured both by himself and his family before he was able to produce the glaze which for so long had eluded his grasp, and many men, both before and since, have worked equally hard, and for a far longer time, without meeting with the slightest success as the reward of their efforts. Had these men had even an elementary knowledge of the properties of the materials they were using they would have been saved endless worry and expense, and although they might not have obtained glazes which gave them perfect satisfaction—because to do so with certainty and in a short time implies a very full and complete acquaintance with the behaviour of these materials under varying conditions—they would, at any rate, have been able to secure a glaze of some kind, whereas in many cases they have failed to produce a glaze which would adhere at all to the clay on which it was fired.

From what has just been written it will be surmised that recipes are of little value unless the purchaser is prepared to spend time in adapting the information given to the conditions obtaining in his own yard. Indeed, there are few more misleading purchases than recipes, for whilst appearing to give the fullest information, they have an unfortunate habit of "not working" when the information given is put into practice.

Most books of recipes usually give a large number of different recipes for what appears to be precisely the same kind of work. This is specially noticeable in connection with the manufacture of bodies and glazes in the pottery as distinct from the brick and sanitary ware trades, and is due to the fact that different men, working with slightly

different materials—or, what amounts to the same thing, with materials of the same name obtained from different sources—will necessarily modify any recipe which they may all have obtained originally in as many different ways as there are workmen. These differences, slight as they may appear to be, are essential to successful working, because few of the materials used in glazing are pure or absolutely constant in composition. Where the composition of the materials used is exactly known, each of them having been subjected to a periodical analysis, the glazer is able to modify his recipes accordingly with great accuracy, but, unfortunately, the majority of glazers have no knowledge of chemistry —the science which lies at the root of all successful glazing—and have no clear ideas as to the effect of small proportions of impurity in their materials.

Usually they think that if they obtain their materials from one source, that no further care is necessary, but a very little study of the formation of such materials as china clay, Cornwall stone, and felspar will convince them of the foolishness of this position.

The very noticeable variations in the porcelains of different countries are largely due to these variations in the composition of the raw materials used. This shows the necessity for adapting any recipes to meet local needs, and also explains why certain results can only be obtained in certain localities. Often the variations are so subtle that they cannot be definitely ascertained, though their effects may be very pronounced. For example, the author recently found a material sold to a glazer as ball clay was almost destitute of plasticity—the chief characteristic of true ball clays.

The few recipes given in the later pages of this volume have been carefully selected because they are each typical of their kind. They must be regarded as "starting points" from which glazes suited to particular cases may be built up, rather than as absolute recipes which can be used without

alteration. Experience has shown that such typical glazes, carefully chosen, are far more valuable than a much larger number of recipes in many ways resembling each other, for from what has already been written, the reader will see how useless such an array of miscellaneous recipes would be, except as matters of curiosity, or, under some conditions, of historical interest.

Those who wish to take up the subject of glazing should always bear in mind that the value of a recipe or collection of recipes, the source of which is not known, is simply this: it enables a keen observer to find a starting point from which to commence experiments on his own clay, and under conditions obtaining in his own works. In only a few cases will he be able to use a recipe without alteration, and unless he knows enough about the materials employed to calculate the formula of a glaze (in a manner to be described in a later article) he will waste an enormous amount of time in trying different recipes, all of which may ultimately form the same glaze when the materials are drawn out of the kiln.

This is, indeed, one of the most striking characteristics observed in the study of collections of recipes for bodies and glazes, that whilst apparently exceedingly different. yet many of them, when subjected to the unifying action of the kiln, actually produce the same glaze with all its defects or advantages, and long roundabout methods of preparation are often employed simply because the glaze-mixer is unaware of what is taking place within the kiln. There is no need to enlarge on this point at this stage; it will be clearly evident to the reader as he continues the fascinating study of glaze compositions.

The preparation of glazes for use on china, earthenware, and other white-ware is purposely omitted from the present volume, its scope being limited to glazes applied to brick-clays, tiles and coarse pottery made of natural clay and not of a specially compounded mixture.

CHAPTER II.

THE MATERIALS USED.

Bearing in mind the suggestions in the previous chapter, it will readily be understood that, in the first place, it is necessary to know something of the properties of the materials used for the manufacture of glazes, and as these materials are very numerous it must suffice here to mention only those which are most frequently employed, leaving the more expensive and rarer ones for those who have time and money to expend upon them.

A glance into a glazer's book reveals the fact that the compositions of most glazes is anything but simple. The materials used are not often spoken of outside the trade, and their names are, therefore, unfamiliar, and apparently difficult to remember, but a little patience will work wonders in this direction, and the careful reader will have no difficulty.

According to the nature of the clay, and the purposes for which the goods are to be used, glazes may be divided into two large classes:—

(a) Glazes containing lead compounds.

(b) Glazes free from lead compounds.

The lead-glazes, being much more easily melted, are used for many purposes where a "harder" glaze would be impossible, but the fact that they are poisonous, except under very limited conditions, renders them quite unsuitable for use on domestic ware. Indeed, the amount of suffering caused to the workers in places where lead glazes are used is so great that it is questionable whether their use should be permitted at all were it not for the difficulty of obtaining glazes free from lead which are really satisfactory at such low temperature as those which contain this ingredient.

The chief forms in which lead is used in the manufacture of glazes are (1) Litharge or Lead Oxide, (2) Red Lead or Minium (another oxide of lead), (3) White Lead or Lead Carbonate, and (4) Galena or Lead.

Litharge Sulphide is a compound of lead and oxygen, containing, when pure, 93 per cent. of lead. It is not easily melted by itself, but when mixed with finely ground silica (see later), and heated, it combines with it and melts, the temperature at which the melting takes place varying with the proportions of litharge and silica in the mixture, and on the purity of the materials. In colour it is a dirty yellow or pale red, according to the way in which it has been prepared. The yellow variety is generally known as *massicot*. At a bright red heat it melts, but on cooling becomes crystalline, except, as already stated, in the presence of silica, with which it combines to form a glaze or glass-like material.

Red Lead, otherwise known as *Minium* or *Mennige*, contains 90 per cent. of lead and 10 per cent. of oxygen, and is a brilliant red, heavy powder, not easily mistaken for anything else. On heating it becomes very dark brown, but resumes it original colour on cooling, unless it has been heated to 400 deg. Cent., when it parts with some of its oxygen, and is converted into litharge. In consequence of this, the commercial product is never quite pure (as it always contains some litharge), and unless bought from dealers of high reputation, red lead is frequently found to contain large quantities of red oxide of iron, brick dust, etc., which are entirely useless for glazing purposes so far as the particular properties required in red lead are concerned.

White Lead is a basic carbonate of lead which nominally contains 80 per cent. of lead, but which in practice is of a greatly varying composition, and for which a cheaper carbonate containing 78 per cent. of lead is often substituted. The difference in cost of these two carbonates is solely due to the method

of preparation, the latter material not being capable of being used as a paint like white lead, but either may be used indifferently in the manufacture of glaze, as it is the lead itself, and not the other elements combined with it, which are required.

Care must be taken that lead carbonate is obtained, and not one of the other "whites" which are often used as a substitute for white lead in painting. These other "whites," such as "zinc white" or "baryta white," are quite unsuitable for replacing lead in glazes.

Galena, or lead sulphide, is sometimes recommended in old glaze bocks, but its use is accompanied by so many disadvantages that it is unwise to employ it, except for very cheap goods, at the present day. Its chief advantage is that users are not subject to so rigid a supervision by H.M. Factory Inspectors as when other lead compounds are used. Galena is an ore of lead found in large quantities in some districts, and from it almost all the metallic lead now in use is prepared. Being an ore, it is seldom pure, and the 13 per cent. of sulphur it contains is a constant source of trouble when galena is mixed with other materials to form a glaze.

As lead compounds alone do not form a good glaze, they must be mixed with some suitable materials in order that a true vitrified glaze may be produced. The most frequently used materials for this purpose are various forms of silica, such as sand, flint or quartz, and various clays and other materials rich in alumina.

Sand is generally too uncertain a composition to be used for any but the cheapest goods, though there are certain deposits or beds of sand in which the material is particularly free from impurities. These "white sands" are invaluable where they can be cheaply obtained, as they consist of almost perfectly pure silica.

The commoner red or yellow sands are only suitable where the goods are of a red or yellowish

colour, or where the colour does not matter. They are far less pure, and often contain fragments of other rocks, the influence of which on a glaze it is difficult to predict. Hence when purchasing sand for glaze-making purposes, care should be taken to see that fine pure "white sand" is obtained, and for some glazes it is desirable that such a sand should contain at least 98 per cent of silica, and should all pass through a No. 80 sieve when mixed with water.

Flint is another form of silica which has probably been dissolved in water at some time, and has gradually been precipitated around the dead body of a small sponge or other animalcule, the amount of deposit increasing as time has passed, until finally a lump of flint sometimes as large as a child's head has been formed.

Flints are usually fairly pure silica, and do not often contain more than five per cent. of other materials, of which chalk is the chief. For some reason, which does not appear to be plain, preference it always given in potteries for French flints. Careful analyses of a large number of flints from both France and England fail to show any noticeable superiority in the former, so that it is probably one of those many cases of insular prejudice, and nothing more, which prevents our English potters and glazers from taking kindly to the use of native flints.

As flint-stones are extremely hard and somewhat difficult to grind, it is not customary for clayworkers in this country to grind them for their own use, and they are usually bought ready ground. Formerly, they were heated to redness and dropped into cold water, the coarse fragments so formed being ground between dry stones, but at the present time the flints are always ground in water, whereby much of the fine dust which would otherwise be lost is preserved, and the grinding process is rendered far less dangerous to the workmen.

When "water-ground" flint is purchased, care should be taken to see that it is sufficiently dry, or difficulties will arise in its use. The best firms will sell on a basis of five per cent. moisture, and the powder should not contain much more than this amount unless the purchaser is aware of it.

Quartz is a crystalline form of silica, and is one of the purest forms found in Nature. Quartz crystals appear to the ordinary observer to be made of glass, and are remarkable for the accuracy of their form and their transparency and brilliance.

Quartz is more used in Germany than in this country, as flint is more popular here. From a glazer's point of view, there is little or no difference between finely ground sand, flint and quartz, providing that the materials are sufficiently pure, as these three are only different geological forms of the same substance—silica.

On account of the methods of their formation, however, sand is generally least pure, and so is used for the cheaper articles; flint may be used for all but the most particularly delicate work, for which powdered quartz will be found to be the most suitable. For all ordinary purposes the use of the best qualities of ground flint leaves little or nothing to be desired.

The aluminous earths, which are added to give brilliancy or "body" to the glaze, are either clays, felspars, or Cornish stone. A few other materials, such as cryolite, are occasionally used, but these can generally be readily replaced by one or other of the ones just named.

Clays form so large a class that they can receive but slight treatment here. The coloured, or common clays, are only capable of being used in glazes where the impurities they contain will not spoil the glaze, and so that they meet with but limited application.

China clay or *kaolin* is a very pure form of clay found largely in the South-West of England, and shipped chiefly from Teignmouth and other

Devonshire and Cornish ports. It derives its name from being very similar to the clay chiefly used in the manufacture of Chinese porcelain and of English "china-ware." Beds of very pure kaolin are also found in central Europe and in various parts of America, but the Cornish and Devonian deposits are so abundant that there is no necessity to import this material from other lands.

China clay requires very careful purification by washing and sifting before it is suitable for use in pottery work, but as this purification is carried out by the makers, it is sold ready for mixing with the other ingredients of the glaze.

When freed from mica and other impurities, china clay is a soft, cream-coloured mass, with very little plasticity, and, in many ways, resembles a soft rock rather than a clay. On heating it loses its yellowish colour and becomes white, though its "whiteness" may be considerably increased by the addition of a minute proportion of cobalt to the clay before burning.

The composition of china clay is commonly given as :—Alumina, 39 per cent. ; silica, 46 per cent. ; water (combined), 14 per cent. ; and impurities, 1 per cent. ; but these figures are typical rather than actual, and some samples vary greatly from this composition. Hence it is desirable to have an analysis of the material when fresh sources of supply are contemplated. Quite recently a firm offered for sale as "best china clay" a material containing only 24 per cent. of silica, and which, whilst of value for certain purposes, was quite useless for that for which it was proposed to use it.

China clay is valuable in glaze-making, as it is rich in both alumina and silica, and practically free from impurities of a harmful nature. Its slight plasticity helps the glaze to adhere to the goods before putting them into the kilns, but is not sufficient to cause the glaze-coating to shrink too much, as would be the case where a highly plastic clay was used.

For "bodies," the use of china clay is invaluable, as it is one of the whitest-burning clays known, and is in great demand as the basis for the body of white glazed bricks made of an inferior, or cheaper, clay. It does not shrink enough when used alone in a body, and so is always mixed with a more plastic clay (such as ball clay), sufficient of this latter being added to enable the "body" to contract to exactly the same extent as the clay it is intended to cover.

Ball clays occur in great variety, the better known ones being the "blue" clays of Devon, Dorset and Hampshire, and the "black" clays of North Wales.

Ball clays are simply plastic kaolins, or china clays, which have obtained their plasticity during their transportation from the place where they were formed to the place where they are found. The name is due to the shape in which the clay is obtained from the workings, as, being soft, it is cut into irregular cubes or "balls" in order that it may be brought to the surface.

The variety of ball clay most prized by glazers is that known as "best selected white Devonshire," which is, in its raw condition, perfectly black, owing to the organic matter which it contains, but which burns out in the kiln, leaving a fine white mass.

Ball clays are often richer in alumina than the china clays or kaolin, but their average composition is not much different, except that they usually contain rather more organic matter and water.

When used alone they shrink much more in the kilns than do the china clays, and so are chiefly employed at the present time for giving more plasticity to the bodies in which they are used. This very plasticity is often a source of danger, as it is accompanied by impurities, in the form of iron compounds, which are very difficult to trace, and to other impurities introduced during the transport

of the clay from its source and formation to the clay pit from which it is dug.

Ten or twelve years ago, ball clays constituted half the mixture used for making white "bodies" for glazed bricks and other articles, and the small amounts of impurities in them prevented pure white effects from being obtained, hence in more recent years it has been the practice to replace the ball clay by the purer china clay as far as possible, thereby making it easy to obtain goods of the purest white.

At the present day the chief use of ball clay by glazers is to impart the necessary toughness, adhesion, and plasticity to the body-mixture, only sufficient being added to secure these effects, and an excess being avoided on account of its deleterious effect on the colour. Where coloured goods are made, the ball clays may be used in larger proportions.

When fresh supplies of ball clay are purchased they should be tested by moulding them with a definite weight of water into a small bar, about 5 in. by 1 in. by 1 in., measuring this accurately, and carefully comparing its size when fired in the kiln, with a similar one made of the previous batch of ball clay. Unless a test of this kind is made, the great variations in composition of ball clays will make a serious difference in shrinkage in different samples sufficient to cause serious loss in the glazed goods for which it is used.

Ball and china clays should also be tested for fineness, and when mixed with three times their weight of water, should leave no appreciable residue on a sieve with 120 holes to the running inch.

Buff-burning and red-burning clays are occasionally used for covering other clays of which goods are made. They are used alone or after mixing with felspar, flint, or other materials, in order that they may shrink to exactly the same extent in the kiln as the article on which they are used. The glazer who understands the method of

mixing and applying white bodies will find little or no difficulty in preparing bodies with red or buff clay, so that no special description of the uses of these coloured clays need be given. The application of colouring matters to bodies will be dealt with later.

Manganese clay is seldom seen in this country, though very popular abroad for producing brown glazed goods. The percentage of the manganese which causes this brown colour varies greatly, and necessitates an analysis of the clay before it can be safely used. It is commonly added to a white body in amount sufficient to produce the tint required, any alteration in the shrinkage of the clay caused by this addition being remedied by the replacement of some of the ball clay by flint or other non-plastic material. The further uses of manganese will be referred to under the head of Colouring Matters.

Felspar is not—as is commonly supposed by glazers—a single substance, but is the name of a large class of minerals of similar characters but of different composition, so that when a man states that he uses "felspar" in a glaze, it is just as though, when purchasing fruit, it was a matter of the greatest indifference whether he received apples or currants.

Fortunately for most glazers, the "potters' materials merchants" know what is required in most cases, and supply the right kind of felspar or a mixture of suitable characteristics for the purpose in hand, so that but little real difficulty is experienced in practice when dealing with reliable firms.

The most typical felspar is Orthoclase, or potash felspar, which contains about 16 per cent. of potash, 18 per cent. of alumina, and 65 per cent. of silica, and this is the particular felspar which is commonly understood when the word "felspar" is employed in clayworking. Albite is another variety, in which soda takes the place of potash,

whilst in Labradorite and Anorthite this is replaced by lime, yet all these are grouped together by mineralogists under the family name of felspar. This is because they all possess many characteristics in common, and are formed in a similar manner from different varieties of granite by the action of the rain, sun, and air.

When exposed for long periods to the action of the weather, the felspars are still further decomposed, and, by losing the alkali they contain, are transformed into more or less pure china clay or kaolin. Hence felspars have an intermediate composition between granite and china clay.

The felspar used in this country is chiefly imported from Norway and Sweden, but similar materials from other districts are becoming increasingly common. The pinkish tint sometimes seen is due to a minute trace of iron, and may be ignored, though the cream-tinted felspar is to be preferred for the best work.

Felspar is hard, somewhat sandy in nature, and gives a clear jingling sound when several pieces are shaken together. It is difficult to grind, and so is usually bought ready for use, but in this case it is essential to test it for fineness, as some firms have a tendency to send out material which has been over-heated in the drying process, and so will not pass through the sieve.

Owing to its lack of plasticity, felspar must not be used in very large proportions in a glaze, or it will shell off before the goods go to the kiln. Its chief function is to give a brilliant and waxy appearance to a glaze, and to act as a flux, binding the various particles of clay, etc., in the body or glaze together.

Heated alone, it melts at about 1,300 deg. Cent. (Seger Cone 9), according to its purity and composition, and yields an opaque whitish glass, often filled with minute bubbles.

It is of especial value to the glazer, as it enables him to introduce alkali into his mixtures

without the trouble of fritting, and on this account is greatly esteemed as a flux, in spite of its somewhat high price.

Cornish Stone—often called Cornwall Stone, and sometimes Pegmatite, Growan Stone, China Stone, or simply "Stone"—is the substance resulting from the decomposition of a granite rock by natural agencies, and resembles both felspar and china clay in composition, being produced from the same source.

In composition it contains much less alkali than felspar, but more than china clay, and though very variable, the best samples, when placed on the market, usually contain about 5 per cent. of potash, 18 per cent. of alumina, and 75 per cent. of silica, together with small amounts of lime, soda, magnesia, etc. As mined, the stone is richer in mica and other materials which have to be removed by careful selection, sometimes aided by washing, before it can be considered fit for use.

Cornish Stone is more easily ground than felspar, and, when perfectly dry, resembles flint in appearance, but feels less "harsh" when wetted and rubbed between the fingers and thumb. It varies enormously in density as well as in composition, so that it is often troublesome to use, but its relatively low price and its value as a flux are such that it is used in enormous quantities by glazers.

In bodies, the chief function of Cornish Stone is to render them more compact and of closer texture —thus giving them a good "ring"—and in glazes it is important as containing ingredients which are allied to body (clay) on the one hand, and to the fusible substances (glaze) on the other, and thus its presence in a glaze gives solidity and close adherence of the glaze to the article on which it is fired.

When fired at a very high temperature (1,500 deg. Cent. Seger Cone 19) Cornish Stone fuses into a solid white vitrified mass (it may, in fact, be used as a rough glaze), and the best samples behave

precisely similar to felspar when heated alone. When mixed with other substances to form a glaze it requires the addition of lime compounds, such as whiting, to enable it to run sufficiently, and the addition of felspar lowers the temperature at which it can be used. By the addition of borax its melting point may be lowered to almost any required temperature.

It is thought by many clayworkers that Cornish Stone and felspar are mutually interchangeable in glazes and vitrified bodies, but this is by no means the case. This is due to the large proportion of mineral matter greatly resembling mica, which is always present in Cornish Stone and absent from felspar, and on treament with sulphuric acid this stone behaves so entirely different from a mixture of felspar, kaolin, and flint, that it seems hopeless to expect to substitute such a mixture for the natural stone, though the possibility of doing so is a consummation devoutly to be wished.

When opaque, white glazes (vitrified bodies) are composed of felspar, clay, and flint, they usually warp, crack, and refuse to lie properly on the goods; if a sufficient proportion of Cornish Stone be added to such bodies they will generally lose these objectionable defects, and produce a perfectly satisfactory result. Such strange behaviour—considering that felspar and Stone so greatly resemble each other—can only be explained on the supposition that the internal combination of the different elements of which they are composed is different in the two minerals, and that it is, therefore, unreasonable to suppose that they can be substituted for one another. Whatever may be the true explanation of this curious behaviour, it has been proved beyond a doubt by innumerable practical tests that, except under most unusual conditions, *Felspar and Cornish Stone are not interchangeable in glazes and "bodies."*

This little-known fact deserves a far wider publication, as it explains why so many experimental

glazes and bodies have failed to give satisfactory results.

Cornish Stone is one of the most variable substances used in the clay industry, and new batches of material should never be made up at once into glaze without a small test portion being first used. If this precaution is not observed, the careless glazer will some day have the mortification of seeing all his goods coming spoiled out of the kilm because of an unexpected variation in the quality of his stone. The statements of certain merchants that the stone they supply is perfectly constant in composition are by no means strictly true, and, in any case, the making up of a small quantity of glaze or body from new materials as they are received into the works is a matter requiring but little labour, and is well worth doing, in order to avoid the difficulty just mentioned.

Whiting, often called Paris White, is one of the many forms of carbonate of lime which are found in various parts of the world. It is closely allied to chalk, limestone, and a number of other carbonates, and is a valuable agent for reducing the temperature at which a glaze melts. It must not be confused with Plaster of Paris, which acts in a similar manner, and which will be dealt with later.

When heated alone to a high temperature (800 deg. C. or Seger Cone 015) whiting loses carbon di-oxide, and is converted into quicklime, which is quite infusible, but in the presence of siliceous materials combination takes place, and a more or less vitrified mass (according to the relative proportions of the whiting and other substances) is produced. Whiting is, in fact, one of the cheapest fluxes known.

Whiting may easily be distinguished from most of the other ingredients of glazes and bodies by the effervescence produced when a little hydrochloric acid or sulphuric acid is poured upon it.

To obtain the maximum fluxing action from whiting it is necessary to heat it to high tempera-

ture, or to add some more easily fusible substance to the material—felspar is commonly employed for this purpose—but the action once started, goes on with ease and rapidity, producing ideal glazes under comparatively wide variations of temperature.

When properly prepared it is extremely fine, and when mixed with a little water gives a smooth, milky paste, very pleasant to the touch, and quite different from flint, which it somewhat resembles in appearance.

Plaster of Paris, or Gypsum, is another compound of lime, but possesses properties very different from whiting. It is chiefly noted for its "setting" properties, which enable it to be used in the construction of moulds, casts, etc.

In years gone by it was thought that some plaster of Paris must of necessity be added to a glaze to make it adhere to the goods, but this idea has long ago been discarded, and as plaster has many disadvantages accompanying its use, the number of glazers who employ it is rapidly becoming less.

Weight for weight, it is less active than whiting, and this fact may explain its value in certain cases where whiting gives too much contraction ; it would, however, be cheaper and better to use less whiting rather than to employ plaster in such a glaze.

The large proportion of combined sulphuric acid which plaster contains—in the best samples it is never less than 45 per cent.—tends to make glazes containing plaster somewhat dim, or filled with whitish specks of semi-crystalized matter, which can only be avoided by particular attention during the earlier stages of the firing, and when once formed can never be entirely removed. This defect is characteristic of sulphur compounds in glazes, and on this account it is wise never to allow the proportion of sulphates to exceed 5 per cent. of the weight of the (dry) glaze, and, wherever possible, to avoid their use altogether.

For this reason, plaster of Paris should, in most cases, be replaced by two-thirds of its weight (or less) of whiting in glazes and bodies.

Magnesia is generally found when glazes and bodies are analysed, but its presence is accidental rather than otherwise, and the proportions present are almost always very small. Most of the ingredients of glazes and bodies contain small quantities of magnesia and its compounds, but the amount in most cases is insufficient to affect the properties of the materials.

Magnesia compounds act as weak fluxes, but possess the curious property of allowing materials to vitrify without losing their shape, and a little magnesia is on this account used to replace part of the whiting in some bodies. This is, however, seldom done, and, as a general rule, magnesia compounds are regarded as useless by the ordinary glazer, who accordingly neglects them.

Soda and *Potash* compounds are largely used in the earthenware industry in order to lower the melting points of a glaze. As such compounds are all soluble in water they cannot be used direct (with the exception of felspar and Cornish Stone, both of which contain potash, or soda, or both) but require to be fritted with other constituents of the glaze before they can be applied to the goods. Soda is generally employed in the form of sodium carbonate, or "soda," whilst potash is usually added in the form of nitre or saltpetre. *Salt* is useless when mixed with a raw glaze, and is better replaced by soda in frits. When used for glazing, salt is thrown into the fire of the kiln, where it decrepitates, and so applies itself automatically to the goods. Borax is a well-known soda compound; its use and composition are described under the heading, "Borax."

For further details regarding the use of soda and potash compounds, see under "frits" (later), but it should be borne in mind that when it is desirous to avoid fritting, the only way to introduce these

alkalies into a glaze or body is by means of Cornish Stone (which contains 5 per cent.) or of Felspar (which contains about 16 per cent.), as all other potash and soda compounds to be met with in commerce are soluble in water, and so cannot be used.

The solubility of these materials causes them to be drawn to the top of the glaze during the drying of the goods, and so prevents the glaze from being properly mixed. Indeed, it may be said to "unmix" itself whilst drying, and thereby causes some parts to be fluxed, whilst others remain unfused during the firing. With insoluble materials this cannot happen, and it is fortunate for the glazier that in felspar and Cornish Stone he has two materials which can supply him with reliable, insoluble fluxes containing alkali in relatively large proportion.

Zinc Oxide is a white, or creamy, powder, which has gained some reputation as an "anti-craze," but its chief value is in making glazes slightly opaque without affecting their melting points or other properties.

Being a very light powder, a small quantity of zinc oxide will spread through a large quantity of glaze, and the addition of 5 to 20 per cent. of this material to an ordinary transparent glaze will prevent black spots of iron compounds showing through, and will give the articles a colour more nearly resembling stone. At temperatures above Seger Cone 9 it is a useful flux, but too expensive to replace any of the fluxes previously mentioned. It cannot be used to make glazes completely opaque and white because it is naturally of a slightly yellowish tinge, but for producing canes or straw-coloured goods it is particularly useful.

Barium compounds in the form of Barium Carbonate or Barium Sulphate, are frequently used as fluxes to lower the melting point of a glaze, and are very successful at the higher temperatures employed for glazed bricks.

Barium Carbonate (found in nature as *Witherite*) may be used in the form of the ground mineral, but the precipitated form is much purer and better in every way, as it is much finer.

Barium Sulphate (commonly spoken of as *Barytes* or *Sulphate of Barytes*) is obtained by grinding "heavy spar," or as a by-product of several industries. The crude material must usually be washed well before it is fit for use, but it may be obtained ready prepared from the dealers in potters' materials. It contains a large proportion of sulphur, and should not be used where this element is a disadvantage, but for many of the ordinary hard-fire transparent glazes it is largely employed. Barium carbonate is practically free from sulphur, and so frequently replaces the sulphate.

Barytes is difficult to grind, and many samples on the market are extremely gritty and badly contaminated with iron. These should not be used, or the goods will be stained. Water-ground barytes is generally better and smoother than the dry-ground material.

Both the sulphate and carbonate are dense white powders, and require a high temperature to bring about their combination with the other ingredients of the glaze, but combination having once been secured a very brilliant glaze is produced. Being so highly refractory, barytes act to some extent as an opacity-producing substance, and should be omitted from glazes which are fired under Seger Cone 7 (1,270 deg. Cent.).

On account of their great density, barium compounds show a strong tendency to settle to the bottom of the glazing tub, and require the slip to be kept constantly stirred whilst in use. The addition of a little clay to glazes containing barytes will enable the mixture to be kept more even in composition; if the clay makes the glaze too hard a portion of the flint may be removed.

Borax and *Boric Acid* are not used to any large extent in the manufacture of hard glazes, but they enter into the composition of many frits and glazes which mature at a relatively low temperature. They are specially valuable for replacing lead compounds where these latter are, for various reasons, undesirable.

Boric acid in many ways resembles silica in its behaviour in the kiln, but it acts at far lower temperatures. In a similar manner replaces borax felspar in low temperature work.

Both boric acid and borax are easily soluble in water, and cannot be used in the raw state; they must be melted with some of the other ingredients in order to form an insoluble glass or "frit." The choice of ingredients must depend largely on the nature of the glaze, but as a general rule the fritting temperature should be kept as low as possible in order to save fuel; this means that only some and not all the ingredients of the glaze will be heated together to form the frit.

Boric acid and borax are also of great value in "doctoring" hard glazes which do not "sit well" on the goods, and consequently show cracks or other symptoms of unsuitability. Where it is desired to prevent a glaze from crazing, and yet to keep it perfectly clear, the addition of a little boric acid will be generally found to act in preciselv the same manner as silica (flint), but without increasing the melting point of the glaze. Boric acid may also be used for lowering the melting point of a glaze without causing the defects producible by an excess of felspar or other alkaline flux. The labour of fritting is, however, serious, and fritted glazes are avoided whenever the heat is sufficient to render them unnecessary.

Commercial borax loses nearly half its weight on firing owing to the large proportion of water it contains. Calcined borax is free from this water, but suffers from other disadvantages, notably its extreme hardness and higher cost.

A number of other materials, such as *Glass, Cryolite, and Fluor Spar*, are employed in special cases to impart translucency to bodies or to act as fluxes, but their employment requires special skill, and is accompanied by much uncertainty. *Bone Ash* is used in large quantities in certain branches of the pottery trade, but as it is mixed with the materials of which the ware is made, and not placed on the top like a "body" or glaze, a description of its uses scarcely comes within the scope of "The Glazer's Book."

FRITS.

It has already been explained that in some instances the materials cannot be simply mixed together in order to form a glaze, but they must receive a preliminary melting (or "fritting") together before they are in a fit state to use.

The object of this "fritting" is to convert those ingredients of the glaze which are soluble in water into insoluble compounds, so that when the glaze is made up into a slip the materials will not "un-mix" themselves during the drying of the glaze on the goods, as would inevitably take place were water-soluble materials employed without some previous treament.

The term "frit" means fried (it is closely allied to the word "fritters"—a well-known form of potatoes), and conveys no idea as to the composition of the frit itself. Indeed, any glaze composition which has been melted previous to use is legitimately termed a "frit." It is necessary to be perfectly clear on this point, because many recipes for glazes state that a certain proportion of "frit" is to be used without giving the composition of the frit; in such cases it is impossible to make a glaze from the recipe until a sufficient number of trials have shown which of the many hundreds of frits now known was intended.

This shows the folly of purchasing recipes from men who have obtained them illegally, as the chances of their proving wrong or incomplete is very great.

Whenever the direction is given to "frit" such and such ingredients of a glaze, it is to be understood that these materials are to be melted together into a more or less clear glass. This glass is to be afterwards ground to a powder sufficiently fine to pass through the sieves used in the preparation of an ordinary glaze.

The kiln used for fritting varies in different places and according to the amount of material to be fritted. It does not pay to heat up the kiln for very small quantities of material, so that it is usual to prepare as much frit at a time as will last for several months.

The ordinary frit kiln used in the potteries consists of a reverberatory furnace or "hearth," heated by the flame and hot gases from a neighbouring grate, and from which the molten mass is allowed to run by withdrawing a plug near to the bottom of the hearth.

The time required for fritting varies enormously, but with large quantities is seldom less than two hours for each charge when the hearth is in full work. The molten frit is usually received in a tank of cold water, which makes it disentegrate, and therefore more easy to grind, besides preventing it from adhering to the sides of the receiving vessel.

For experimental purposes, the materials may be put into a thick fireclay crucible, and this placed in a suitable part of the ordinary kiln, or a specially arranged kiln may be built for this purpose.

An excellent "kiln" for small quantities of frit consists of a large crucible, to the bottom of which is fastened a clay tube, so that any melted material may run from the crucible through the tube into a receiving vessel placed below. Such an arrangement gives a continuous supply of frit, the raw materials being placed in the crucible and the frit

being taken away as required. A little care is required in heating such a crucible to prevent any fuel from getting mixed with the frit, but no difficulty is experienced with a reasonable amount of care.

When a crucible full of frit is heated in an ordinary kiln it will generally be nearly cold before it can be withdrawn. In such a case, the crucible and its contents must be broken with a heavy hammer, the pieces of clay separated from the frit, and the latter carefully ground, preferably in a porcelain cylinder ball mill.

In the case of frits used in connection with delicate colours it is often necessary to protect them from all contact with the flame of the kiln by firing them in special crucibles; they must also be carefully covered.

It is usually desirable to line the crucible with flint by washing it out with a slip of this material.

Many lead glazes are fritted in order to make the lead less soluble, and require special care. The The time for fritting should, with glazes containing lead, be as short as possible, as this material has such a searching action on the brickwork of the kiln.

The fritted mass should be of a rough-glass appearance, and may be ground in a ball-mill or between two grindstones made of granite. In either case the process is exceedingly slow, owing to the hardness of the material, and a charge of frit often takes 30 hours or more to grind. If light-coloured or white glazes are desired no iron must be used for grinding.

The ground material must pass through a sieve with at least 120 meshes per running inch, any particles remaining on the sieve being returned to the mill and re-ground. When all the material has passed the sieve it is well mixed, and either allowed to stand until sufficient water can be poured off to make it into a slip weighing about 28 ozs. per pint, or it may be dried by warming or on plaster slabs.

Dry-ground frit is not to be recommended, as that which is ground in water is smoother, finer, and better.

In the production of frits four points are essential to success—(1) Cleanliness, (2) Fineness, (3) Economy, and (4) Uniformity. The first of these can only be secured by avoiding the use of iron tools, by keeping the materials always covered, and by working in a clean part of the premises.

The fineness of the frit will depend on the condition in which the grinding apparatus is kept. It is a great mistake to use only those portions which grind the most easily; they do not represent the true composition of the frit. All the charge must be ground and passed through the sieves before any of the fine material is used for admixture with the glaze.

To secure economy and regularity of composition, it is necessary that the frit kiln should be run continuously, day and night, until a sufficiently large quantity of frit has been made. The chief expense for fuel is in the heating up of the brickwork composing the kiln, and once this is hot the amount of fuel required is relatively small; hence as much frit as possible should be made at one time—preferably a six months' supply.

The ingredients of frits are the same as glazes, and the recipes are similar in each case, though, as the chief object of the fritting is merely to convert the soluble materials into an insoluble form, there is no necessity to frit the whole of the ingredients of the glaze. Usually, the whole of the soluble materials are fritted with about twice their weight of flint or flint and clay, but so much depends upon local circumstances that no definite rule can be given.

Some glazers frit the whole of the glaze, as they believe that in this way they obtain a material in which the possibility of un-mixing in the dipping tub is reduced to a minimum. Where a glaze contains extra dense materials, such a fritting is often

valuable, though costly. It is used much more abroad than in this country.

The subject of frits and frit-melting is large and interesting, but it must suffice here to say that frits are usually divisible into two classes — the alkaline and the boracic. The former contains soda and potash compounds, the latter contains either borax or boric acid, or both.

With certain colouring materials different effects are obtained with an alkaline and a boracic frit, and only actual testing can determine which of the two is to be used under any given conditions when a definite shade of colour is required.

According to the alkaline or boracic nature of the frit, varying proportions of china clay, whiting, felspar, or stone are added in order to produce a sufficiently fluid mass.

The materials should be roughly crushed before being mixed and fed to the kiln. For most purposes a No. 20 sieve is sufficiently fine. The mixing should be as thorough as possible, and the sifting repeated two or three times after mixing, in order to save much stirring or mixing of the material whilst it is in the frit kiln. This stirring of the semi-molten mass in the kiln in order to mix it is a common source of contamination by iron from the pokers, with consequent staining of the glaze.

FLUXES.

Sometimes materials are mixed to form substances which are incomplete glazes, but which are able to reduce the melting point of other materials to which they may be added. Such materals are known as fluxes, and are especially valuable in the manufacture of white and coloured glazes.

Fluxes are, as a rule, rich in lead, deficient in flint or sand, and often, though not always, contain some easily fusible glass, such as borax or flint glass.

Here are two of obviously different composition, which yet may be used indifferently in many cases with equally good results:—

	Flux A.	Flux B.
Red Lead	30 lbs.	16 lbs.
Flint	10 lbs.	16 lbs.
Borax	20 lbs.	28 lbs.

Like all glaze materials containing soda, potash, borax, nitre, etc., these fluxes must be melted and reground before they can be made into slip for use. If not so melted (fritted), the soluble portion will rise to the top of the glaze when drying, and will give an uneven glaze.

A true flux cannot be used alone, as it is incomplete; it must be mixed with some less fusible substance before it becomes a true glaze. Thus the above fluxes may be mixed with varying proportions of colouring metallic oxides, or they may be used in connection with a suitable recipe to produce a colourless glaze.

Where the labour of fritting is undesirable, many frits or fluxes may be purchased ready for use from the dealers in potter's materials. If desired, glazes and bodies may be purchased in a similar manner and satisfactory results obtained even though the composition of these glazes remains unknown. Some firms find their best course consists in using a purchased glaze as a basis and adding to it such other materials as make it suitable for their purpose. The chief disadvantages of this method of working are, (1) the high cost of the prepared glaze; (2) the greater difficulties in adapting it, owing to the absence of knowledge of its composition, and (3) in case of anything going wrong, it is often extremely difficult to lay the blame on the right persons. In spite of these drawbacks large quantities of ready made glazes are purchased.

Colouring Materials are best purchased ready for use, as they are very difficult to prepare satisfactorily, and if unskillfully treated in their

preparation it will be impossible to obtain constant shades of colour.

The potter's materials merchants make a speciality of this kind of work, and provided that only reliable firms are dealt with, satisfactorily uniform materials will be obtained.

The following list shows the prepared oxides generally employed and the colours obtainable from them. They may be blended to some extent so as to obtain other shades of colour, but the more delicate or complicated tints are preferably obtained by the use of special colours purchased ready for use :—

For *whites*—Arsenic, oxide of tin, tin ashes *, oxide of bismuth.

For *browns*—Iron and manganese oxides, and coloured clays (siennas and umbers).

For *yellows*—Titanium, antimony and iron oxides, lead chromate, and (for orange yellows) uranium oxide.

For *reds*—Ferrous sulphate, or red copper oxide under strong reducing conditions.

For *pinks*—Chromium and tin oxides mixed.

For *blues*—Cobalt oxide, with or without opacity-producing materials like zinc oxide.

For *greens*—Chrome oxides, bichromate, copper oxide, cobalt oxide, and yellow clays.

For *blacks*—Cobalt and maganese or iron chromate (mixed). A perfect black glaze is unknown.

For *gold*—The metal gold is applied in various forms, but can only be used at very low temperatures.

* "Tin ashes" is usually made by heating lead with one-third of its weight of tin until the whole is fully oxidized into a yellowish brown powder. Hence tin ashes cannot be used in a "leadless" glaze.

Other colours are made by mixing these or other chemicals, or by putting a glaze which is naturally colourless on a clay which will develop a colour with the glaze. The "cane" or "straw" colour of most sanitary articles is produced in this way, though a little manganese is sometimes added to make the colour more distinct.

Recipes in which the proportion of these various colouring agents are employed will be given later, when the nature of the glazes in, under, or over which they are employed has been considered in further detail.

In purchasing the foregoing chemicals, it is very important that they should be obtained from firms specialising in potter's materials. Chemicals bearing the same name purchased from a chemist's shop will usually need grinding or other treatment before they can be used.

CHAPTER III.

TESTING THE MATERIALS.

The complete testing of the materials used in glazing requires all the facilities of a specially fitted chemical laboratory and a knowledge of practical chemistry which few glazers are likely to possess.

The most satisfactory method of preventing errors consists, therefore, in the making up of 50 lbs. or so of glaze or body each time a new lot of material is received and applying this to specially marked goods. If these are satisfactory after they have been drawn from the kiln, no further test is necessary ; if they are unsatisfactory inquiry may be made as to the cause. For this reason it is always wise to order new material several weeks, or even months, before the present stock is exhausted, so that in case of error no serious loss may occur. Firms who only purchase small quantities of material run far greater risks than those who order in larger quantities at less frequent intervals.

Bodies and glazes frequently prove defective because the glazer has not paid any attention to variations in the amount of *moisture* in the materials. This is always present in the materials used for glazes and bodies, and is apt to vary from day to day, as well as from sample to sample. The necessity of keeping all materials in a place where they will be dried and remain dry is not always realised as it should be, and unless this matter is carefully watched variations in the composition of the glaze or body to the extent of 10 per cent. may easily be met with, and may cause entirely different results to be produced in the kilns.

For example, suppose a new purchase of felspar is made, and this fresh portion contains 10

per cent. of moisture, whereas the material on previous occasions has only contained 3 per cent.; if no allowance is made, the glaze will be deficient in felspar, and consequently in brilliance, simply because the new material contains only nine-tenths of its normal amount of felspar, the remainder being water, which is useless in the fired glaze.

The variation in the proportion of moisture is especially noticeable in the clays, though all water-ground materials, such as flint, spar, and stone, often vary because of imperfect drying or of exposure to the weather.

In moist, foggy weather the moisture present in the materials is greater than in summer or frosty weather, so that no definite proportion can be taken as normal or standard, though most of the firms supplying these materials will, if asked, guarantee them to contain less than 5 per cent. of water on their leaving their works. They cannot, of course, give any guarantee as to the amount of rain they will absorb on the journey, and the accuracy with which such materials are weighed is not such as would enable the user to ascertain whether they had been rained on and become partially dry in transport.

As, in order to determine the amount of moisture in a sample, the quantity used must be small, weighed with great accuracy, dried with the utmost care and re-weighed, equally accurately, it is necessary to employ special appliances. These can be obtained from any dealer in scientific apparatus.

The weights used are preferably those of the metric system, of which the unit is 1 gramme. The older grain-weights may be used if desired, but will be found less convenient when once the gramme system is understood.

In this connection it may be convenient to note that

1 oz. = 28·4 grammes.
1 lb. = 453·7 grammes.

The balance for weighing the materials used by a glazer should be of the pattern shown in Fig. 1, and should be sensitive to half a milligramme, or one-hundredth of a grain. Care must be taken to use such a delicate balance carefully, and not to overload it by weighing more than about 3 ozs. at a time. The outer case is intended to keep away all dust, and should be kept closed when no weighing is being made. With care such a balance

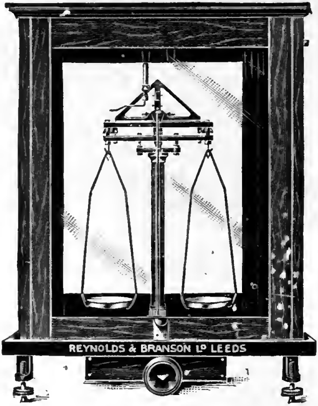
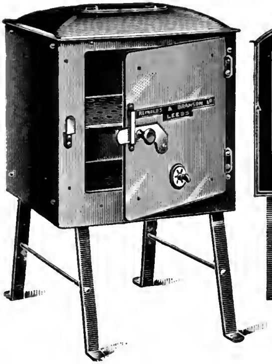


Fig. 1. Accurate Balance.

will last many years, but it should be tested several times a year by weighing one or more of the weights, so as to ensure its being in good working order, or it may be tested by the Inspector of Weights and Measures for a small sum. Such a balance can be obtained in various qualities, and are sold by most scientific instrument makers; the one illustrated is made by Reynolds and Branson,

Ltd., of Leeds, and costs £2 12s. 6d. It should stand on a very firm shelf or table where it will not vibrate unduly.

The small oven for drying the portion of raw material used in the test may be either made at home or purchased, according to the user's fancy. The one we illustrate is an improved form made by the same firm. It consists essentially of an iron box, placed inside another one, so as to leave about



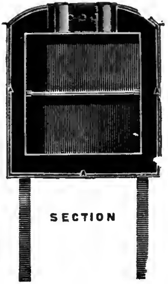


Fig. 2 —Drying Oven. Fig. 3.—Section of Oven.

an inch air-space all round between the two. A cover must be provided, or the boxes fitted with a door, as shown in Fig. 2. Fig. 3 shows a section of the oven. The perforated shelf is not absolutely necessary, though convenient when a number of materials are being tested at the same time. A thermometer is passed through a cork which fits an opening in the top, and is so fixed that the lower end of the thermometer is about half an inch above the portion of the stove containing the material to

be tested. The whole arrangement is mounted on a stand, and is heated by a small upright Bunsen gas-burner giving a blue flame, and capable of being regulated with ease and accuracy. This burner must be so arranged that the temperature inside the stove (as shown by the thermometer) does not vary more than one degree from 110 deg. Cent., no matter how long the stove is in use, and for this purpose the whole apparatus must be placed where it will be free from draughts.

In order to ascertain how much moisture a material contains, a small glass dish, $2\frac{3}{4}$ in. diameter, with flat bottom and vertical sides, and made of thin Bohemian glass so as to withstand heat, is placed on the left-hand scale of the balance, carefully weighed, and the weight written down. A little of the material to be tested is placed in the dish, and the whole again weighed, and the new weight written down just above the previous one. The increase in weight should be about 5 grammes (75 grains) and more material should be added or some taken away until about this amount is in the dish. Its exact weight must then be ascertained as described.

In choosing a sample of material for testing, it is necessary to take a true sample, that is, one from near the middle of the main package, and it is far better to take out two or three pounds from various parts of each package, mix them up thoroughly, and then take a portion from them than it is to take a sample direct from the original package. It must always be recognised that the whole value of the test depends on the portion tested accurately representing the contents of the package from which it is taken, and that any errors due to getting an "unfair" sample will be thrown on to the test.

The dish, with its contents, is now to be placed in the stove, and kept at a temperature of 110 deg. Cent. for about four hours, after which it is taken out, placed on a clean tile, and covered with a large glass (to keep off all dust), and weighed as soon

as it is cold. It must not be weighed whilst warm, or the warmth will affect the air in the balance, and give a wrong result. Special glass vessels for cooling the material may be employed if desired. They are termed "Dessicators" or "Exsicçators," and prevent the material from absorbing water from the air.

The weight of the glass and its contents after drying having been written down, the glass is again placed in the stove, and heated to the same temperature for one hour more, after which it is allowed to cool under a glass as before, and again weighed. If it has lost any weight in the second period of drying it must be put back for another hour, and the heating and weighing repeated until no loss of weight is noticed.

The difference between the last weighing and that of the glass and material before they were placed in the stove will be the amount of moisture (providing the operation has been carried out properly), and this result, when multiplied by 100 and divided by the weight of material originally in the glass, will give the percentage of moisture present in the material.

An actual example will make this clearer:— The empty glass dish, in this case, weighed 32·724 grammes; with the material it weighed 37·738 grammes. The following figures were obtained during the drying:—

After drying	4 hours	....	36·345	grammes
,, ,,	5 ,,	....	36·272	,,
,, ,,	6 ,,	....	36·267	,,
,, ,,	7 ,,	....	36·266	,,
,, ,,	8 ,,	....	36·266	,,

Consequently the weight of material used for the test was 37·738, less 32·724, or 5·014 grammes, and the loss of weight due to driving out all the moisture was 37·738 less 36·266, or 0·464 grammes, and the former number divided into the latter, multiplied by 100, gives 9·2 per cent. of moisture in the material.

Some glazers, who are sufficiently careless not to trouble to test their raw materials for moisture so as to correct variations in the composition of the glazes or bodies, will do so when they realise that they are paying fancy prices for water sold to them under the guise of china clay or felspar. Thus a firm recently wrote to a number of dealers asking for quotations and samples of felspar. Various replies were received, and the following among them:—Firm A. asked 94s. for a felspar containing 4·2 per cent. of moisture, B. asked 90s. 6d. for one containing 8·6 per cent. of moisture, and C. asked 88s. 6d. for a sample containing 12 per cent of moisture.

Assuming that in other respects the materials were of the same quality, which was the cheapest?

Deducting the percentage of moisture from 100 in each case will give the weight of dry felspar. The relative value is the percentage of dry felspar in the material divided by the price in each case; this relative value being really the amount of pure material which can be obtained from each firm for the payment of a given sum. Thus:—

A's material	...	95·8	÷	94	=	1·02
B's do.	...	91·4	÷	90·5	=	1·01
C's do.	...	88·0	÷	88·5	=	·99

and as more actual felspar can be obtained from A. for a given sum, this is really the best material. Consequently "the dearest is the cheapest," because it contains more of the required material per ton than do either of the other two, and the purchaser of materials B and C would be paying for water he did not want.

The Loss on Firing undergone by some materials is so great that unless allowance is made for it the whole recipe is useless. One of the most troublesome of these materials is Borax, which loses 47 per cent. of its weight in the kiln owing to the large proportion of "water of crystallization" is contains. This water is not moisture, and cannot be

driven off at 110 deg. Cent.; it is only expelled at a much higher temperature. The result is that, when making a mixture for a frit (borax, being soluble, must always be fritted with some other ingredients of the glaze before use), it is necessary to use nearly double the amount of borax which would be required if calcined borax were used.

Other materials in common use which lose weight in the kiln are felspar, stone. clay, soda, and most crystalline substances.

CHAPTER IV.

COMPARING RECIPES.

Before passing on to the composition of the glaze itself, it is desirable that some consideration should be given to the general composition of glazes, in order that some species of classification may be obtained. This is all the more necessary as there are on the market and scattered throughout the literature of clayworking, innumerable recipes and glazes which, when fired, produced almost identically the same chemical compounds, and have to all attempts and purposes the same final composition. Yet some of these same recipes call some of the specified ingredients by such unusual names that it is difficult to procure them, and even when this can be done it is often possible to substitute a much cheaper material or mixture, and yet produce the same result after firing.

The chief worker in this attempt to produce order out of the chaos of glaze recipes was the late Prof. Seger, of Berlin, who conceived the idea that all true glazes are chemical compounds, and therefore must have a composition which can be expressed in a certain chemical manner. He had not carried his investigations very far when he found that no chemical formula could accurately represent the composition of the glazes found to be most successful in actual use, but the idea proved so valuable an instrument for investigating the nature of different glazes that it is still in use at the present day as a convenient method of classifying glazes into certain well-defined groups.

In the first place, it is quite impossible to compare glazes accurately by merely noting the varying proportions of such ingredients as felspar, Cornish stone, etc., because these are

not elementary substances, but complicated mixtures or compounds of a number of other substances. Thus, both felspar and Cornish stone contain alumina, silica, lime, and potash, though in different proportions, and in order to judge of the effect brought about by a change in the composition of the glaze, or to compare two recipes, it is necessary to know the proportion of each of these separate ingredients of the materials mentioned in the recipes.

Again flint, though nominally pure silica, is seldom perfectly free from lime, and often contains 3 per cent. of this material, so that in comparing glazes it is not enough to assume that both quartz and flint are pure silica; the one may be, the other is not.

The first essential to a comparison of two or more glazes is a knowledge of the true composition of the ingredients specified. This can only be obtained from analysis of each of the materials used, though in a few instances it is sufficiently accurate to assume that the materials have a certain composition. Thus, if it is known that perfectly pure materials (or materials of at least 98 per cent. purity) are used, there is no need to have a complete analysis made specially, though this is really the safest plan.

In comparing recipes (when it is known that the ingredients named refer to standard materials, and not to impure ones, or to those obtained from some special source), it is often sufficiently accurate to assume certain compositions to certain materials.

Some of these are shown in the following Table. Care must be taken in the use of this list of compositions in actual practice that the materials actually used are of exactly the composition given in the Table, or serious errors in calculation will result. Thus, china clay varies greatly in composition, and though its average composition is given in the Table, it does not follow that the clay used contains the

same ingredients in the same proportions unless direct analysis has shown this to be the case

APPROXIMATE COMPOSITIONS OF GLAZE MATERIALS.

Material.	Silica.	Alumina.	Lime.	Magnesia	Potash & Soda.	Water, etc.
Felspar ...	65	18	$\frac{1}{4}$	—	16	$\frac{3}{4}$
Cornish Stone	76	16	2	$\frac{1}{4}$	3	$2\frac{3}{4}$
China Clay (Kaolin)	45	40	$\frac{1}{2}$	—	1	$13\frac{1}{2}$
Ball Clay ...	45	39	$\frac{3}{4}$	$\frac{1}{4}$	$1\frac{1}{2}$	$13\frac{1}{2}$
Flint ...	95	—	5	—	—	—
Whiting ...	—	—	56	—	—	44

The ingredients collected in the last column under the heading, "Water, etc.," do not enter into the composition of the glaze when it is drawn from the kiln, and are not, therefore, of direct interest to the glazer.

TO FIND THE TRUE COMPOSITION.

In order to ascertain what is the ultimate composition of any glaze recipe, it is necessary to calculate how much of each of the constituents of each substance mentioned in the recipes present. This may be done, as already explained, from the analysis or from the above Table, according to the nature of the case. Thus, supposing a recipe directs that 25 lbs. of felspar be used, this is equivalent to 25-100ths each of the materials mentioned in the above Table on the same line as the word Felspar. In other words, 25 lbs. of

felspar are exactly equivalent to 16·25 lbs. silica, 4·5 lbs. alumina 0·06 lbs. lime, 4·0 lbs. potash and soda, and 0·19 lbs. water, etc.

In a similar manner, all the other materials mentioned in the recipe can be split up into an equivalent amount of their respective ingredients, and the totals of each ingredient will then give the ultimate composition of the recipe or glaze.

Thus, taking the Hard Clear Glaze recipe given below as an example; this is seen on re-arrangement to have a composition shown by the following chart or Table—the totals at the bottom showing the ultimate composition :—

HARD CLEAR GLAZE.

Felspar	25 lbs.
Cornish Stone	50 lbs.
Flint	5 lbs.
Whiting	15 lbs.
White-Burning Ball Clay ...	5 lbs.

Recipe.	Silica.	Alumina.	Lime.	Magnesia.	Potash & Soda.	Water, etc.
25lbs. Felspar	16·25	4 50	·06	—	4 00	·19
50lbs. Cornish Stone	38·00	8·00	1·00	·12	1·50	1·38
5lbs. Flint ...	4 75	—	·25	—	—	—
15lbs. Whiting	—	—	8·40	—	—	6 60
5lbs. Ball Clay	2·25	1·95	·04	·01	08	67
100lbs. Total	61·25	14·45	9·75	·13	5·58	8·84

Calculating in this way, the ultimate composition of the glaze is seen to be that shown in the line marked "Total," and provided that the temperature and other conditions in the kiln are suitable, it will not much matter from what

substances these ingredients are obtained, provided that the same ultimate composition is reached.

Not only so, but certain inert substances may also be present with the proportion of the remaining constituents of the glaze. Thus, for some purposes, it does not matter whether the lime be added in the form of whiting or of plaster of Paris, providing that the correct quantity of lime is used, as the carbonate portion of the whiting and the sulphate portion of the plaster go into the last column of "unused constituents." With some goods, however, the presence of sulphates is objectionable, and plaster cannot then be used, though in proportion to its lime content it is as good a flux as whiting.

In a similar manner, barium carbonate is able to replace barium sulphate or barytes, provided an amount corresponding to the barium content of the latter is employed.

It is obviously incorrect to simply replace one lime or other compound by an equal weight of another, because this would introduce a different quantity of the element required into the glaze. The correct amount must be calculated from a knowledge of the composition of the various substances which can be obtained from a table of molecular weights. Thus, 136 lbs. of plaster of Paris are the exact equivalent of 100 lbs. of whiting.

It will be noticed that the temperature of firing has a great influence on the extent to which different compounds of the same material may be interchanged in a glaze. On this account such replacements cannot be made with much freedom in low temperature glazes, and even with the harder glazes some difficulties arise if, for instance, some Cornish stone is replaced by felspar and flint, as the new mixture may have a different co-efficient of expansion to the original, and so may craze whilst the other remained perfectly sound.

WHAT IS A FORMULA?

Chemists have a species of shorthand, which they use in putting information on paper, in which each element is represented by the first letter of its Latin name, or by two letters when a single one is not convenient. Thus P is the letter representing Phosphorus, and as it cannot at the same time be used for lead, of which the Latin name is Plumbum, this latter element is represented by Pb. In a similar manner Iron is represented by Fe (Ferrum), Calcium by Ca, Potassium by K (Kalium), Sodium by Na (Natrium), Silicon by Si, etc.

When a substance is a compound of two elements it is represented by the appropriate letters (technically called "symbols"), following each other; thus FeO represents a compound of iron and oxygen, CaO represents a compound of calcium and oxygen (lime), and so on. But the symbols convey more than this information, inasmuch as they each represent a definite quantity of the substance they represent. Thus O does not merely stand for "oxygen," but for a definite weight of this substance. The actual weight represented differs with each symbol, and will be found in Tables given on another page, under the headings, "Molecular Weights" and "Atomic Weights." From these Tables it will be seen that O represents 16 weights of oxygen, and FeO represents $56+16=72$ weights of this particular iron oxide. What is the actual unit of weight does matter for the purpose of glaze calculation, and it is, therefore, convenient to consider it as "pounds."

When a symbol is followed by a small figure it means that that symbol must be counted as many times as the number following it indicates. Thus H_2O means that the substance represented by this formula $H+H+O$, or as $H=1$ and $O=16$ lbs. the substance represented by H_2O (water) contains twice 1 ($=2$) lbs. of hydrogen to each 16 lbs. of oxygen.

In a similar manner Silica, represented by SiO_2, contains 28 lbs. of silicon to each twice 16 (=32) lbs. of oxygen, and Alumina, represented by Al_2O_3, contains twice 27 plus thrice 16 lbs. of aluminium and oxygen respectively, or 54 lbs. of aluminium to each 48 lbs. of oxygen.

From this it will be seen that the formula of a chemical compound is a short means of writing down the proportions in which the different elements combine together. Glazes, being more complicated, are not represented by such simple formulæ as those just given, but the same method of calculation is employed.

The chief difference is the grouping of the ingredients, not into separate elements, but into separate groups of elements, the most important being (a) the alkalies, having a formula of the RO type, in which R stands for the alkali metal, such as calcium, potassium, sodium, etc.; (b) metallic oxides of the R_2O_3 type, in which R usually represents the metal iron or aluminium (it will be remembered that aluminium oxide or alumina has the formula Al_2O_3); (c) non-metallic oxides of the RO_2 type, and in the calculation of glazes almost entirely confined to silica (SiO_2), though boric oxide (B_2O_3) is sometimes included in this group, as it acts in many ways like silica.

The use of the term "formula" in this connection is not quite the same as that in chemical text books, though in many respects it is very similar, the real difference lying in the fact that it is not strictly correct to consider glazes and bodies as accurate chemical compounds, and therefore the use of a formula does not convey quite the same meaning as it does when applied to true compounds. For most purposes, however, this inaccuracy of statement may be overlooked in order to gain the advantages of this method of calculation.

It has already been found that in the case of a Hard Clear Glaze recipe, composed of felspar,

Cornish stone, flint, whiting, and ball clay, the true or "ultimate" composition must be found as shown in the previous table. In this case the ultimate composition is as follows :—

TABLE A.

Silica	61.25
Alumina	14.45
Lime	9.75
Magnesia	.13
Potash and Soda	5.58
Water, etc.	8.84
	100.00

It is, of course, quite possible to compare different glazes effectively by simply comparing their ultimate compositions in the above form, but this involves the consideration of so many figures that it is much easier, and in some ways more satisfactory, to reduce these figures to simpler terms—in other words, to calculate the formula. This is done by dividing each of the constituents in the ultimate composition by its molecular weight, and then dividing each of the results by the lowest one.

The molecular weights of the various materials used in glazes and bodies must be ascertained from a Table. In this instance the ones required are :—

TABLE B.

Silica	SiO_2	Mol. Weight	= 60
Alumina	Al_2O_3	,, ,,	= 102
Lime	CaO	,, ,,	= 56
Magnesia	MgO	,, ,,	= 40
Potash	K_2O	,, ,,	= 94

Dividing the figures in Table A by those in Table B, the following results are obtained:—

Silica	SiO_2	1·021
Alumina	Al_2O_3	·141
Lime	CaO	·174
Magnesia	MgO	·003
Potash	K_2O	·059

In this particular instance, as orthoclase felspar was used, and this is essentially a potash felspar, it is sufficiently accurate to consider the whole of the "potash and soda" in the recipe's ultimate composition as potash.

For the reasons already given, it is unnecessary to include the substances expressed under the heading "Water ,etc.," as these do not enter into the composition of the finished glaze, being driven off by the heat of the kiln. They are, therefore, only of secondary importance at this stage of the calculation.

Dividing the results thus obtained by the lowest one worth consideration (=·059)—the small figure connected with the magnesia is insignificant, and may be added to the lime, or may be omitted altogether—the result comes as follows:—

Silica	SiO_2...........	17·3
Allmina	Al_2O_3	2·4
Lime	CaO...........	3·0
Potash	K_2O	1·0

At this stage two paths are open—the formula may be left as it is, or, acting on a suggestion of Dr. Seger, the fluxing materials may be added together, and the whole formula divided by the total, thus:—

$$\begin{array}{ll} 1{\cdot}0\ K_2O & \\ & 2{\cdot}4\ Al_2O_3 \quad 17{\cdot}3\ SiO_2 \\ 3{\cdot}0\ CaO & \\ \hline \text{Total}\ \ 4{\cdot}0 & \end{array}$$

which, divided by 4·0, gives:—

$$\left.\begin{array}{l} {\cdot}25K_2O \\ {\cdot}75CaO \end{array}\right\} \ 0{\cdot}6Al_2O_3, \quad 4{\cdot}3SiO_2$$

This gives the standard pattern of formula, and by reducing all recipes to these simple terms, or as near to them as possible, comparison of different

recipes is greatly assisted, and the approximate value of an unknown glaze or body can often be ascertained with fair accuracy.

When glazes contain lead (symbol PbO), this is added in with the other fluxes in the first section of the final formula. Thus, in the case of a simple lead glaze, composed of :—

Ball clay	1 lb.
Lynn sand	2 lbs.
Litharge	3 lbs.

the same method of calculation as that just given would be adopted, but it would be slightly simpler in actual working.

In this case the ultimate composition of the glaze would probably be :—

RECIPE.	Silica.	Alumina.	Lime.	Magnesia.	Potash & Soda	Lead Oxide.	Water, &c.
1 lb. Ball Clay	·45	·39	·01	—	·02	—	13
2 lbs. Lynn Sand	1 90	·03	·01	—	·01	—	·05
3 lb. Litharge	·03	—	—	—	—	2·90	·07
Total ...	2·38	0·42	0·02	—	0·03	2·90	0·25

Dividing by the respective molecular weights, this gives :—

Silica	·040
Alumina	·004
Lead oxide	·013

The lime, magnesia, and potash are in too small proportions to be calculable, and may be

omitted. Dividing these last results by the smallest (=·004), and re-arranging so as to place fluxes first and silica last, this gives :—

$$3{\cdot}25\ PbO\ 1{\cdot}0\ Al_2O_3\ 10{\cdot}0\ SiO_2$$

Or, dividing this by the total fluxes (as Seger suggests), the formula becomes :—

$$1{\cdot}0\ PbO\ 0{\cdot}31\ Al_2O_3\ 3{\cdot}1\ SiO_2$$

In cases where analyses of the materials are available they should be used. The modified method of calculation may then be expressed in the following terms :—

FORMULÆ FROM PERCENTAGE COMPOSITION OR RECIPE.

(*a*) *Find the composition of each substance used in the recipe.*

(*b*) *Add together all the same constituents when they occur in different ingredients in the recipe.*

(*c*) *Divide the total amount of each constituent by its molecular weight (which will be found in the Table).*

(*d*) *Divide the results of (c) by the smallest result obtained.*

The result will (after re-arranging) be the required formula.

The following, fully worked example will make this clearer. A glaze has the following composition ; find its formula :—

White lead	100 lbs.
China clay	4 lbs.
Flint	11 lbs.
Cornwall stone	50 lbs.

The materials are found on analysis to have the following compositions :—

White Lead :—

Lead oxide	86·3	per cent.
Water	2·3	,, ,,
Carbon dioxide	11·4	,, ,,

China Clay :—

Alumina	39·0	per cent.
Silica	46·2	,, ,,
Potash and soda ...	0·6	,, ,,
Water	14·2	,, ,,

Flint :—

Silica	96	per cent.
Lime	4	,, ,,

Cornwall Stone :—

Silica	75·0	per cent.
Alumina	18·5	,, ,,
Lime	0·4	,, ,,
Potash and soda ...	7·1	,, ,,

From the foregoing analyses it is now necessary to calculate how much of each of the particular constituents named will enter into the glaze formed. Thus, the 100 lbs. of white lead requires no calculation, but the 4 lbs. of china clay must be resolved as follows from the analysis just given. This may be done by multiplying each line of the analysis of the material by the figure named in the recipe (in this case 4), and dividing the result by 100. Thus :—

Alumina 39·0 by 4÷100=1·56 lbs.
Silica 46·2 by 4÷100=1·85 lbs.
Potash and Soda 0·6 by 4÷100=0·02 lbs.
Water 14·2 by 4÷100=0·57 lbs.

Similarly the 11 lbs. of Flint given in the recipe is composed of :—

Silica 11 by 96 ÷ 100 = 10·56 lbs.
Lime 4 by 11 ÷ 100 = 0·44 lbs.

Also the 50 lbs. of Cornwall Stone, treated in the same manner, may be represented by :—

Silica	37·50 lbs.
Alumina	9·25 lbs.
Lime	0·20 lbs.
Potash and soda	3·05 lbs.

The first stage (a) in the calculation having been accomplished by means of the foregoing analyses (though the composition of white lead could have been equally well found from the Table of Molecular Weights previouslv referred to), it is next necessary to calculate as given under the heading (b) above, and add together the different constituents. This is best accomplished by the use of a sheet ruled as shown below, into which each material and its constituents may be inserted. Thus :—

Weight of Material used.	Lead Oxide.	Lime.	Potash & Soda.	Alumina	Silica.
lbs. 100 White Lead ...	86·3	—	—	—	—
4 China Clay ...	—	—	0·02	1·56	1·85
11 Flint	—	0·44	—	—	10·56
50 Cornwall Stone	—	0·20	3·05	9·25	37 50
Total ...	86·3	0·64	3·07	10·81	49·91

It will be noticed that water and carbon dioxide are omitted, as these being volatized in the kiln, do

not enter into the composition of the glaze itself. Similarly there may be other constituents in other glazes, such as magnesia, iron compounds, etc., which, not being present in the one under consideration, are not dealt with. If present they would have separate columns for their accommodation.

It is now necessary to convert these ordinary weights into such a form as can be expressed by symbols, and this is done as in (c) by dividing the total weight of each constituent by its molecular weight. Thus :—

Total Weight of Constituent from above Table.	Molecular Weight.	Result of Division.
86·3 lbs. Lead Oxide PbO	222	0·39
0·64 lbs. Lime, CaO	56	0·01
3·07 lbs. Potash and Soda Na^2O & K^2O	78	0·04
10·81 lbs. Alumina, Al^2O^3	102	0·11
49·91 lbs. Silica, SiO^2	60	0·83

Expressing these results in symbolical form, the formula of the glaze becomes:—

$$\left.\begin{array}{l} 0{\cdot}39\ PbO \\ 0{\cdot}01\ CaO \\ 0{\cdot}04\ NaKO \end{array}\right\}\ 0{\cdot}11\ Al_2O_3\quad 1{\cdot}83\ SiO_2.$$

As it is inconvenient to leave the formula in just this form, it is customary to divide the figures just given by the total of the first three alkalies (0·44), so that in all glaze formulæ the total RO group shall always be unity. This gives the final formula as :—

$$\left.\begin{array}{l} 0{\cdot}886\ PbO \\ 0{\cdot}022\ CaO \\ 0{\cdot}092\ NaKO \end{array}\right\}\ 0{\cdot}25\ Al_2O_3\quad 1{\cdot}88\ SiO_2$$

$$\overline{1{\cdot}000}$$

WHAT A FORMULA TEACHES.

Having obtained the formulæ of each of a number of glazes, what do these teach? In the first place, it will soon be found that the most diverse recipes often produce in the kiln the same identical glaze. At the same time this method of calculation is only of value when the composition of the raw materials is accurately known, and not simply judged by analyses of similar substances.

Again, the relative proportions of base (alkali oxide), alumina, and silica in a glaze is shown at once in the clearest possible form by its formulæ, and by this means errors in the composition of a glaze recipe may often be corrected, in a manner impossible without calculating the formula.

Thus, Seger has laid it down as a general rule that however much the ingredients used in making a glaze may vary, yet the final formula arranged on the above plan must be confined within comparatively narrow limits, and suggested that these limits should be—:

For white ware glazes—1·000 RO. 0·1 to 0·4, Al_2O_3 2·5 to 4·5, SiO_2.

For porcelain and high temperature leadless glazes—1·000 RO. 0·5 to 1·25, Al_2O_3. 5 to 12, SiO_2.

Although these limits form good guides for general practice in considering new and untried glazes, there are some instances in which a smaller amount of silica may be employed, as in the example just given.

The calculation of the formula of a glaze is particularly useful when comparing various mixtures, each equally satisfactory, with a view to reducing the cost of the raw materials, as when the correct formula of a glaze suitable for the particular working conditions is obtained it is a comparatively easy matter to calculate what proportion of other materials may be substituted in order that one or more of the more expensive constituents may be

replaced by some cheaper material in cases where this can be done satisfactorily.

DISADVANTAGES OF FORMULÆ.

Although the advantages of formulæ calculations are very great, they are not by any means perfect as a method of accurately comparing different glazes, though in skilled hands they are by far the most valuable of all methods of comparison yet suggested.

The chief difficulty lies in the elimination of many ingredients which are present in too small quantities to be conveniently included in the formulæ, and yet which are not without influence on the glaze or body. Thus the presence of 5 per cent of iron oxide in a glaze would probably not be shown at all clearly in the formula unless special reasons for doing so were given, yet this amount of colouring material may effectually prevent the glaze from being used on certain classes of goods, owing to its being stained by the iron oxide. If the iron were replaced by a still smaller quantity of a stronger stain, such as cobalt, the results in practice would be more marked, but the formula might not show any difference between this blue and a white or colourless glaze.

In the hands of an expert such errors are not likely to be committed, but as these Chapters are written for the ordinary glazer it is necessary to issue a warning against too slavish a dependence upon formulæ, valuable as they are when properly used.

Another difficulty, not always appreciated by those who are enthusiasts in the use of formulæ, is the continual variations in the composition of the materials used. These variations are often too small to show in a formula of the Seger or standard type, but are, notwithstanding, very troublesome to deal with. As, however, they mostly arise in con-

nection with the regular working of the glaze, they will be dealt with in a later section.

A third disadvantage in using formulæ for the comparison of glazes or of different materials for use in glazes is that only the ultimate composition of these materials is considered. Thus, it would appear that felspar or Cornish stone can mutually replace each other in a glaze, providing that the other ingredients be altered to keep the ultimate composition of the recipe at a constant value. This is not the case, and many experimental glazes have failed utterly on this account. This matter has already been referred to in the sections devoted to felspar and stone, but it cannot be too strongly repeated that these two materials are seldom or never interchangeable, and that formulæ calculated from glazes containing them both are only of very limited application. When only one of them is present in a glaze, and this is known, no difficulty is experienced, but the formula of a recipe containing both felspar and Cornish stone is of only small value for comparitive purposes.

This view is quite contrary to that generally held, but it has been confirmed by repeated investigation, and by the results of an extensive practical experience.

Nevertheless, the use of formulæ is increasing, for they are far too valuable to be thrown aside because they require some skill in interpretation. For roughly sorting out recipes into well-defined classes, for the elimination of uselessly complicated recipes, and for the general study of glaze compositions, with a view to their improvement or the elimination of some defect, there is no method at present known which can give so clear and concise a summary of the general properties and possibilities of a glaze as the calculation of its formula.

A glaze formula is, in fact, somewhat similar to a series of two sieves—coarse and fine, used for testing clays—it separates into convenient groups, in a simple and direct manner, substances which

could not otherwise be so readily separated and compared, and just as a sieve will indicate readily the proportion of small stones in a sample of clay, so will the calculation of the formula of a glaze show the relative proportions of fluxes, bases, and silica, and will enable the user to say from direct observation whether a particular glaze is worth further effort and experiment for a given purpose, or whether it is of such a nature that further tests are useless. But just as these two sieves will only effect three separations, so a formula will only effect an approximate classification.

Knowledge of glaze formulæ will not form the basis of a guarantee that a given recipe will produce a satisfactory glaze on a certain clay or at a certain temperature, but it will effectively reduce the number of actual trials which may be necessary in order to adapt a recipe to given conditions, because it will, if properly used, indicate the limits beyond which it is unwise to go under the conditions in which the glaze is to be used.

Such information cannot easily be obtained from a consideration of a recipe alone, and whilst the calculation of the ultimate composition, as given abve, may be of great assistance (especially where a number of substances used in very small proportions are of importance), it is usually much simpler to compare glazes which have been reduced to a standard formula, as their compositions can then be compared in a manner far less cumbersome than is otherwise necessary.

TO CONVERT A FORMULÆ INTO A RECIPE.

From time to time, and especially in the Continental trade and scientific journals, various details are given of experiments made with new composition or new glazes, or of investigations which have been carried out with a view to elucidating certain problems connected with glazing. For reasons

previously given, these results are usually condensed into formulæ, so that a clearer comparison may be obtained without the lesser important substances interfering too much. On this account, if for no other reason, it is necessary that the enterprising and studious glazer should be able to make up recipes which he may be able to use by calculating them from the formulæ supplied.

The reason why investigators prefer to use formulæ as the basis of their work is that they can proceed much more systematically than when they merely increase or diminish the proportion of one of the materials used in a glaze or body. It not infrequently happens that the same element (such as aluminium or silicon) occurs in several of the materials used for a glaze, and as these materials are seldom elementary, but usually of a complex composition, it is difficult to trace the precise effect of a change in their proportions.

Thus, felspar is composed of potash, alumina, and silica, with negligible proportions of other substances, and to increase the proportion of felspar in a glaze or body would at once alter the proportion of potash, alumina, and silica in the glaze. Now it is not convenient to alter all these at once, because, whilst the effect of increasing or diminishing the proportion of any one of them may be easily predicted or studied without serious difficulty, but the production of changes in the proportions of all three so complicates matters that the experimentor is apt to lose track of what is really happening.

When the investigation is carried out on the basis of a formula, on the other hand, it is easy to add or remove any desired constituent in any required proportions without unduly complicating the composition or involving consideration of the changes brought about by the other ingredients of the mixture. Consequently, whilst it is not so necessary, in studying the effect of some substances when added to a glaze, because these contain only one important element, such as whiting, it becomes

almost imperatively necessary when substances of more complex composition are used.

The method of calculation used to convert a formula into a recipe is exactly the reverse of that previously given for calculating the formula of a glaze or body. The calculation is simple, though somewhat tedious to those not used to work of this kind. It is, however, well worth a little study, as it enables many articles of value and interest to be understood in a manner which is otherwise impossible.

Thus a typical glaze formula is the following, which represents an ordinary hard paste glaze:–

$$\begin{array}{l} 0{\cdot}086\ CaO \\ 0{\cdot}062\ MgO \quad 2{\cdot}2\ Al_2O_3\ 15{\cdot}3\ SiO_2. \\ 0{\cdot}852\ K_2O \end{array}$$

This glaze obviously contains (on the assumptions previously made) :—

56 by 0·086 lbs. calcium oxide, or lime.
40 by 0·062 lbs. magnesium oxide, or magnesia.
94 by 0·852 lbs. potassium oxide, or potash.
102 by 2·2 lbs. aluminium oxide, or alumina.
60 by 15·3 lbs. silicon oxide, or silica.

The numbers shown before the word "by" are the Molecular Weights found by adding together the Atomic Weights, as previously described. In practice there is no need to add each up separately, as these numbers can all be found in the Table of Molecular Weights. Multiplying out, it is easy to see that the glaze whose formula is stated above has the following composition :—

Lime	4·816 lbs.
Magnesia	2·480 lbs.
Potash	80·088 lbs.
Alumina	224·400 lbs.
Silica	918·000 lbs.
	1,229·784 lbs.

Or, dividing each line by 100 times the total, and thus converting it into percentages :—

Lime	0·4	per cent.
Magnesia	0·2	,, ,,
Potash	6·5	,, ,,
Alumina	18·3	,, ,,
Silica	74·6	,, ,,
	100	,, ,,

CALCULATING RECIPES FROM A LIMITING FORMULA.

Sometimes the limits of composition are given, as when Prof. Seger, for instance, states as the result of his experience that the composition of glazes for white ware should be contained within the limits of the formula :—

$$1{\cdot}0\ RO,\ 0{\cdot}1 \text{ to } 0{\cdot}4\ Al_2O_3,\ 2{\cdot}5 \text{ to } 4{\cdot}5\ SiO_2,$$

where the symbol RO represents the total fluxes.

What does such a statement mean, and how can the glazer translate it into "understandable language?"

In the first place, it must be understood that no other form of expression can so briefly cover all that this one means, but allowing for a certain amount of loss of information, the glazer may take the limits given in the formula, and from them calculate two recipes, which shall form the bounds outside of which (according to Professor Seger) satisfactory white ware glazes are not likely to be made.

A glance at the above formula will show that it may be split up into two formulæ, each of which will form a "limit" of composition, namely—

(a) $1.0\ RO\ 0.1\ Al_2O_3,\ 2.5\ SiO_2$
(b) $1.0\ RO\ 0.4\ Al_2O_3,\ 4.5\ SiO_2$

Besides these, there are almost innumerable other formulæ, which may be arranged, such as:—

(c) 1.0 RO, 0.1 Al_2O_3, 4.5 SiO_2

which is similar to (a), but has the same SiO_2 as (b), but these three formulæ will suffice for the present.

The first stage of the calculation consists in multiplying each of the numbers in the formula by the molecular weight of the substance following each. These molecular weights must be obtained from a Table, from which it will be found that the molecular weights required are :—Alumina (Al_2O_3) = 102, Silica (SiO_2) = 60, Lime (CaO) = 56, Potash (K_2O) = 94, Soda (Na_2O) = 62, Litharge (PbO) = 222, Carbon dioxide (CO_2) = 44, and Water (H_2O) = 18.

The symbol "RO" may stand for lime, magnesia, potash, soda, lead oxide, or any similar flux, or for any mixtures of these, and thus the apparently simple formula may be converted into an indefinitely large number of different recipes, according to the particular substances intended to be included under the term "RO." For convenience, two distinct cases may be taken, so as to obtain a simple lead glaze and a hard leadless glaze, containing both potash and lime in the proportions of 0.2 K_2O and 0.8 CaO (= 1.0 RO). A softer glaze potash or by lead, but for the moment a simpler glaze will be easier to study.

Acting on this suggestion, and substituting lead oxide or the mixed potash and lime for the RO in the above three formulæ, these become:—

(d)	1.0 PbO	0.1 Al_2O_3	2.5 SiO_2
(e)	$\left.\begin{matrix}0.2\ K_2O\\0.8\ CaO\end{matrix}\right\}$	0.1 Al_2O_3	2.5 SiO_2
(f)	1.0 PbO	0.4 Al_2O_3	4.5 SiO_2
(g)	$\left.\begin{matrix}0.2\ K_2O\\0.8\ CaO\end{matrix}\right\}$	0.4 Al_2O_3	4.5 SiO_2
(h)	1.0 PbO	0.1 Al_2O_3	4.5 SiO_2
(m)	$\left.\begin{matrix}0.2\ K_2O\\0.8\ CaO\end{matrix}\right\}$	0.1 Al_2O_3	4.5 SiO_2

These are only six out of thousands of possible glazes agreeable to the original formula, and in practice it would be necessary to start with these or similar ones, and then alter them step by step until the correct one was found for a certain purpose. This may seem to be an enormous task, and so it is, but it is far shorter and less troublesome than the plan adopted by most glazers, who change and change again without any system worthy of the name, and who depend on almost hopelessly long odds on their getting near to what they require. The method now being described may seem cumbersome, but it is both more certain and more speedy than the "hit and miss method" generally used.

Multiplying each of the above six formulæ in turn by the molecular weights of their respective constituents, the following summary of results may be obtained. The figures in the Table may be taken to represent lbs.) :—

Formula	Litharge PbO	Potash K_2O	Lime CaO	Alumina Al_2O_3	Silica SiO_2
d.	222	—	—	10·2	150
e.	—	19·8	44·8	10·2	150
f.	222	—	—	40 8	270
g.	—	19·8	44·8	40·8	270
h.	222	—	—	10·2	270
m.	—	19·8	44·8	10·2	270

This Table shows that (taking *m* as an example) this glaze contains:—

Potash	19.8 lbs.
Lime	44.8 lbs.
Alumina	10.2 lbs.
Silica	270.0 lbs.

The composition of the others may readily be found by inspection, so that the apparently meaningless formulæ are expressed in this Table in the more familiar form of lbs.

Even this advance does not make the matter clear in some cases, though it does in others, for the materials to be used must next be decided.

WHAT MATERIALS SHOULD BE USED?

The percentage composition of a glaze or body may be ascertained, but it is next necessary to select the materials, as glazes are seldom, if ever, made from the simple oxides, as these would make too refractory a mixture. Besides, these oxides can be found combined in such convenient substances as clay, felspar, etc. In actual practice, the composition of the various materials available must be ascertained by means of analysis. In the present instance it will be convenient to assume that they are of the following composition:—

CHINA CLAY.

Alumina	40 per cent.
Silica	46 ,, ,,
Water, etc.	14 ,, ,,

FELSPAR.

Alumina	18 per cent.
Silica	65 ,, ,,
Potash	16 ,, ,,
Other ingredients	1 ,, ,,

Taking the lead glazes first, and assuming that all the alumina is derived from clay—this is reasonable, for, in the absence of potash or soda, it could not be derived from felspar, and is not likely to have been pure alumina)—of the above

composition the silica equivalent to it may be found by proportion thus :—

Al_2O_3 in clay.	:	SiO_2 in clay.	::	Al_2O_3 in glaze.	:	Equivalent silica.
40	:	46	::	10·2	:	11·7

The silica thus calculated is deducted from the total silica in the glaze and the balance is placed in this last column. These three glazes may be represented thus :—

Formula.	Litharge PbO	Al_2O_3 for Clay.	SiO_2 for Clay.	Water, &c.	Clay.	Silica not required for Clay.
d.	222	10·2	11·7	3·6	25·5	138·3
f.	222	40·8	46·9	14·3	102	223·1
h.	222	10·2	11·7	3·6	25·5	258·3

The silica left over from that required to combine with the alumina to form clay of the composition above given may be considered to be present in the form of a pure sand, quartz, or flint—most probably the latter. The composition of these glazes is, therefore, equivalent to the following three recipes :—

	Litharge.	Clay.	Flint.
d.	222 lbs.	$25\frac{1}{2}$ lbs.	$138\frac{1}{2}$ lbs.
f.	222 lbs.	102 lbs.	223 lbs.
h.	222 lbs.	$25\frac{1}{2}$ lbs.	$258\frac{1}{2}$ lbs.

For most purposes it would probably be sufficiently accurate to divide each recipe by the

amount of the clay it contains, and to consider the following as the final recipes :—

	Litharge.	Clay.	Flint.
d.	9 lbs.	1 lb.	5½ lbs.
f.	2¼ lbs.	1 lb.	2¼ lbs.
h.	9 lbs.	1 lb.	10 lbs.

The potash-lime formulæ are similarly treated, but with the additional complication that the potash used is supplied as felspar, which also contains alumina and silica, and must be calculated in a similar manner to that used for the alumina in the previous example, but in this case the alumina and silica required by the felspar thus calculated are set down, and any balance of alumina and silica is calculated to clay. Any silica still left over is placed in the last column. Hence, the two columns of alumina in the table will be equal to the total alumina in the glaze, and the three columns of silica to the total silica in the glaze. The lime must be calculated to whiting ($CaCO_3$) by multiplying by 1·786. The figures obtained will then show the results set forth in the accompanying table :—

Formula.	Lime.	Whiting.	Potash.	Alumina.	Silica.	&c.	= Felspar.	Alumina.	Silica,	&c.	= Clay.	Other Silica.
e.	44·8	80·0	19·8	22·3	80·6	1·3	124·0	10·2	11·7	3·6	25·5	57·7
g.	44·8	80·0	19.8	22·3	80·6	1·3	124·0	40·8	46·9	14·3	102·0	142·5
m.	44·8	80·0	19·8	22·3	80·6	1·3	124·0	10·2	11·7	3·6	25·5	177·7

Taking the totals for felspar, clay, and free silica (flint), this gives :—

	Felspar.	Clay.	Flint.	Whiting.
e.	124 lbs.	$25\frac{1}{2}$ lbs.	$57\frac{3}{4}$ lbs.	80 lbs.
g.	124 lbs.	102 lbs.	$142\frac{1}{2}$ lbs.	80 lbs.
m.	124 lbs.	$25\frac{1}{2}$ lbs.	$177\frac{1}{2}$ lbs.	80 lbs.

and this, divided by the lowest number in each recipe, gives the following, final recipes with sufficient accuracy for most purposes:—

	Felspar.	Clay.	Flint.	Whiting.
e.	$4\frac{3}{4}$ lbs.	1 lb.	$2\frac{1}{4}$ lbs.	3 lbs.
g.	$1\frac{1}{2}$ lbs.	$1\frac{1}{4}$lb.	$1\frac{3}{4}$ lbs.	1 lb.
m.	$4\frac{3}{4}$ lbs.	1 lb.	7 lbs.	3 lbs.

COMPARING RECIPES AND FORMULÆ.

The glazer who has worked out the foregoing formulæ into recipes will see the practical variations in his recipes which are feasible if Seger's statement (previously given) holds good. He will find that if lead is the main or only RO material used, for a glaze to form within Seger's limits it must not contain more than nine times as much litharge as clay, and that the free silica (flint or sand) may vary from twice the weight of clay in the glaze to ten times this quantity. If a felspathic glaze is made, however, the permissable variations in flint and felspar in proportion to the clay are much less marked. The comparison may be varied somewhat by re-arranging the recipes so as to show the percentage of each ingredient, when it will be found that the figures obtained are so confusing that it is almost impossible to interpret them when they are in percentage form. It was to overcome this difficulty that the use of formulæ was first suggested by Seger.

With the proportion of one ingredient kept constant (as the clay in the final recipes), it is possible to see the effect of adding one or more ingredients, but when merely the total is kept constant (as when the recipes are calculated to a percentage composition), this comparison is well night impossible.

On this account, if for no other reason, every glazer who is young enough to be ambitious should endeavour to understand fully what a glaze formula means, and what it is intended to teach. Incidentally he will, if he is wise, study the disadvantages

of this method of calculation, but will find that the more he studies it and the more familiar it becomes the greater will be its value to him, and the greater the pleasure he can take in the investigations of other men.

SHOULD GLAZES BE EXACT FORMULÆ?

Many clayworkers have at one time or another discussed the desirability of using glazes which correspond in composition to an exact chemical formula, but the attempts which have been made to work with such glazes have not usually been successful. The reasons for this are varied and many, but one of the most important is the fact that glazes and glasses are not definite chemical compounds, but are really solutions of various materials in others, and, consequently, if the materials approach too nearly to a definite chemical composition the tendency to crystallise is so great as to spoil the transparency and evenness of the glaze.

The study of the true composition of glazes from the physico-chemical side has been neglected until comparatively recently, but the researches of various ceramic chemists during the past twenty years have thrown a large amount of light on this subject, and have shown the composition of glazes to be far more complicated than most glazers ever imagined, and have proved that the ascertaining of the real composition of a glaze is not a matter to be lightly undertaken, even by the cleverest glazer alive.

In this connection the study of the behaviour of mixtures of various metals is very helpful, especially when these are in the form of well-known alloys. It has been found that when two metals are mixed in any desired proportions and melted that the molten mass on cooling slowly changes in composition according to the temperature range through which it has cooled, and according to the nature and

proportions of the two metals of which the alloy is composed. First one of the metals separates out in the solid form, and then a compound of the two solidifies, and is called the "eutectic;" after this has been produced as completely as the conditions will permit a solidification of the second metal (if any is left uncombined with the first in the eutectic) takes place.

In this way will be produced in succession one metal, a compound or eutectic, and, finally, the second metal, and according to the temperature at which the solidified portion is removed from the molten mass so the composition of the former will vary.

A similar series of changes takes place in the cooling of a mixture of glaze materials, and the object of the glazer is to obtain as large a proportion of the intermediate compounds in the mixture as possible, so as to avoid the lack of transparency due to the presence of the most infusible constituent on the one hand, or the lack or durability and tendency to excessive movement of the glaze, due to the presence of too much flux on the other. At the same time it is necessary to avoid any formation of crystals which would cause a devitrication of the glaze.

When the composition of this intermediate product is examined, however, it is found to vary within such wide limits that it can scarcely be given a definite composition, such as would be the case were it a definite chemical compound, and the general conclusion of those glaze students who have investigated the matter most thoroughly is that it is really a highly complex "solid solution," in which not only the chemical affinities of the various constituents must be considered, but the physical action of each of the materials produced during the various stages of heating and cooling must also be taken far more largely into account than they have been in the past. On this account, it will probably be found that the glazes of the future, like those of the

present, will not be based on any really definite chemical formula, but will be made from actual trial of different proportions of certain ingredients.

This must not be taken to mean that formulæ are useless. On the contrary, they form the most valuable means we at present possess for simply classifying glazes in which widely different materials are used; but it does not seem feasible to attempt to compound glazes and bodies of a highly accurate chemical composition in which the formulæ contain no fractions, for the whole tendency of modern investigation in glaze composition tends to show that such "chemical compounds" do not exist in reality in glazes, and that if they could be prepared they would have the characteristics of crystalline or devitrified masses, and not of glazes.

Such "feathered" or "crystalline" glazes are often very beautiful from the decorative point of view, and many potters are persistent in their attempts to obtain definite patterns of crystalline work on vases, etc., by taking great pains to include in the compositions of their glazes a material like titanium oxide, zinc oxide, or even manganese, and by cooling very slowly through a range of temperature in which these crystalline forms are most likely to be produced. The most favourable temperature for this class of work is 830 C., with a range of about 40 C. above and below, but the composition of the glazes naturally has a considerable effect on the temperature at which these crystalline compounds separate out.

CHAPTER V.

THE RELATION OF COMPOSITION AND MELTING POINT.

Every glazer is aware that certain changes in the composition of a glaze will effect a marked change in the temperature at which it melts or matures. Thus the addition of infusible substances of a silicious character, such as flint, will generally necessitate the employment of higher temperatures if the glaze is to be completely melted. Similarly, the addition of a metallic oxide (such as soda or lime) will usually lower the melting point of a glaze.

This general "rule" is not, however, invariably applicable, and cases are known to the writer in which the addition of flint has lowered the melting point of a glaze (chiefly because it was excessively rich in whiting, which, having nothing with which to combine, acted as an infusible mass until the flint with which it could re-act was added), and other cases in which the addition of an excess of a flux such as whiting only made the glaze more difficult to fuse. Such cases are, however, immediately recognised when their formula is calculated and the ratio of the RO to the alumina and silica of the glaze is ascertained.

According to Seger, the melting point of a glaze depends on no less than four factors, which are :—

(1) The molecular ratio of fluxing bases (RO) to silica.

(2) The nature of the fluxes used.

(3) The molecular ratio of the alumina to the fluxes and silica.

(4) The ratio of the silica to boric acid when the latter is present.

The molecular ratios are at once found by comparing the numbers in the formula of a glaze.

With a constant amount of bases the melting point varies directly with the silica in the glaze, a normal glaze silica having 2·5 molecules of silica to each 1 of RO base. If too much silica is present, some will separate out and "blind" the glaze, or it will remain unattacked by the fluxes, and will prevent the glaze from fusing properly. Either of these defects may, if not excessive, be cured by the application of a greater heat in the kiln, whereby a fresh set of silicates may be formed.

If a glaze contains too little silica and too much base it loses ductility and tends to boil or blister.

Fluxes differ greatly in their effect on the fusibility of a glaze, even when compared molecularly, as in a formula. Seger found that the following is the order of their strength as fluxes:—

COLOURLESS GLAZES.—Lead, baryta, soda, potash, zinc, lime, magnesia, alumina.

COLOURING OXIDES.—Manganese, cobalt, iron, urania, chrome, nickel oxide.

The number of different bases used exerts a powerful influence on the fusibility of the glaze as a whole, and for satisfactory working at least two bases must be present, though three are much better. The only exception to this is in the case of certain lead glazes, which, owing to the peculiar effect of lead on silica, can be made of lead as the single base. Even then it is often better to use some other base in addition.

In choosing bases, those which give soluble compounds should be avoided when possible, as their use necessitates fritting, which is both troublesome and costly.

The reason why several bases in a glaze act more strongly than when the equivalent amount of a smaller number of glazes is present is not easy to explain, though the fact has been repeatedly proved. Thus, most glazers know that a glaze containing lime, soda, and potash will melt at a

considerably lower temperature than another glaze containing a corresponding amount of either lime and soda or lime and potash, but not all three bases. What really happens is that each base causes a depression in the melting point of the mixture, and the number of these depressions is directly proportional to the number of different fluxes present, and so a glaze is produced which is much more fusible than could be obtained were the number of depressions smaller, owing to a smaller number of fluxes.

The whole phenomenon is dependent on the well-known physical fact that one gram-molecule of a substance dissolved in any solvent causes a constant depression of the melting point of the solvent. The fluxing power of the bases in a glaze is thus found to be related no less to the number of bases present than to the proportions of each actually in the glaze. This is a matter frequently overlooked by the ordinary glazer, who adds an increasing quantity of flux to his glaze in order to lower its melting point, and does not know what to do when he reaches a stage where the addition of flux makes the glaze less fusible. Obviously, the only remedy is to commence using a different flux in addition to those already employed, care being taken to keep the total ratio of fluxes to alumina and silica well within the limits found to be useful by previous experimenters.

Alumina in a glaze has little effect on the melting point, though it undoubtedly acts as a base. Its great value is the amount of variation which it permits in the composition and firing of a glaze, though it is also of much importance when it is required to add silica to a glaze in order to form a tri-silicate, which, without alumina, would unduly tend to crystallise.

Seger finds that the best stoneware glazes contain

$$RO\ 0{\cdot}1{\cdot}Al_2O_3.\ 2{\cdot}5{\cdot}SiO_2,$$

and that the maximum for porcelain glaze is

$$RO\ 0{\cdot}5{\cdot}Al_2O_2.\ 5SiO_2,$$

the maximum being

$$RO\ 1{\cdot}25{\cdot}Al_2O_3.\ 12SiO_2,$$

all of which may be regarded as di-silicates, comparable to $RO\ 2\ SiO_2$.

Boric acid (as previously pointed out) is chiefly of value as a substitute for silica in a glaze in which it is desired to lower the melting point without materially altering its constitution in any other direction. In calculating the formula of a glaze it may usually be included with the silica, but it is best to express it separately on account of its great influence on the melting point of a glaze.

In carrying out experiments on the nature of hard fired stoneware glazes, W. Scheffler found that the silica in this case must not exceed ten times the equivalent of the alumina, or six times the actual weight of alumina, if a transparent glaze, firing under Cone 9, is required. He pointed out that it is remarkable how small a proportion of alumina is sometimes needed to clarify a turbid glaze, as little as 0·02 equivalents often effecting a noticeable difference in this respect. Thus a glaze with the following formula :—

$$\left.\begin{array}{l} 0{\cdot}3\ K_2O \\ 0{\cdot}4\ CaO \\ 0{\cdot}3\ BaO \end{array}\right\}\quad 0{\cdot}40\ Al_2O_3\quad 3{\cdot}5\ SiO_2$$

proved most excellent, both as an ordinary glaze and for use with underglaze colours. It was made from :

Felspar	166·8	parts.
Marble	40·0	,,
Witherite	59·1	,,
China-clay (Zettlitz)	58·8	,,
Sand	90·0	,,

The silica may be raised to 4·0 equivalents—thus making it ten times that of the alumina—but no further.

He also found that higher equivalents than 0·4 of alumina are not practicable for ordinary glazes, as they then tend to become viscous and so retain air bubbles.

Another point emphasised by Scheffler is the necessity of using 0·3 of potash in the glaze, no matter how the rest of the RO portion is made up.

CHAPTER VI.

GLAZES, BODIES, AND DIPS.

Turning from generalities to a few particular cases, the "soft-fired" lead glazes used in such large quantities in both pottery and tile work may be considered.

A SIMPLE LEAD GLAZE.

A particularly well-known glaze of this type, and one that, with but slight modification, is used almost all over the world, is prepared by mixing:—

Ball clay	1 lb.
Lynn sand or flint	2 lbs.
Litharge	3 lbs.

This simple recipe is the starting point of an enormous number of glazes, all of which are really modifications of it which have been made to suit special purposes, such as higher or lower kiln temperatures, more open or less porous goods, cheaper glazes, in which the expensive litharge is replaced by other cheaper chemicals or minerals, etc.

Other modifications depend on the glaze being used when one or more of the ingredients cannot be easily obtained. Thus the use of a different kind of sand in Germany involves the employment of a different proportion, or the substituion of a different variety, of clay. Again, the fact that the composition of both sand and clay differs greatly in different countries, or even in different parts of the same country, has necesitated the use of different proportions, even though the names of the ingredients remain the same.

This change of proportion with change of ingredient (even when the names of the ingredients

are not altered) is well shown in the following recipe, which is the one just given adapted to the conditions obtaining in a French brickyard :—

Local clay	5 lbs.
Local sand	8 lbs.
Litharge	30 lbs.

At the first glance these two recipes appear quite different, yet when the compositions of the various materials are known, they are found to give identically the same glaze. In this instance the clay on which the glaze was fired entered strongly into combination with the litharge at the temperatures used in the kiln, and this rendered the use of less sand and clay in the glaze mixture essential. Further than this, the clay used was so rich in silica that a less proportion of sand than in the first instance was desirable, hence the new recipe appears to be excessively rich in litharge and somewhat deficient in sand.

Another case where the same original recipe has been modified to suit local circumstances occurs in one of the Swiss works, chiefly noted for its doll's tea sets and other small pottery ware, the essentials of which are that it shall be cheap, and shall burn with but little loss. In this case the glaze becomes :

Clay	14 lbs.
Sand	16 lbs.
Litharge	40 lbs.

It will be noticed that the nature of the sand and clay used is not mentioned in the recipe. As a matter of fact, this prevents the composition of the glaze from being known, as it, to the composition of these two important constituents, makes all the difference possible. As a matter of fact, the clay in this instance is a china clay or kaolin of a fairly pure variety, whilst the sand is a quartzose sand, whose only impurity is a little iron. The excess of

litharge used is not due to anything in the glaze materials, or even in the composition of which the articles are made. It is necessary because these articles are fired in all sort of empty places in different parts of the kiln, and consequently suffer an unusually large loss of lead by volatization, so that an extra amount must be introduced (in the form of litharge) to make up for the loss in this direction.

Sometimes other compounds of lead are substituted for the litharge and white lead (a basic carbonate), or red lead (a lead oxide richer in oxygen than litharge) are used. These do not affect the composition of the finished glaze, though they may confer a lower melting point on the glaze in the first instance, or many be used on account of their greater bulk. In many cases they are only used because they are mentioned in the glazer's recipe, and did he know more about the uses and compositions of these various lead compounds, he might oft-times change them to his own or his employer's advantage.

MAJOLICA GLAZES.

These interesting glazes are used on all kinds of clays, and are fired at 700 to 1,150 C. (Cones 018 to 1). They are intermediate in composition between the soft glaze already mentioned and the hard glazes which follow. Being usually coloured they are included in the later section.

Majolica glazes, though abundantly used for tiles, are not regarded favourably for glazed brick work in most cases, because they often craze badly—a defect which is not found in glazes fired at a higher temperature, and in which the complexity of the composition of the glaze need not be so great. In addition to this, glazes fired at higher temperatures are necesarily more similar to the clays in which they are fired, and so can expand and contract with the latter in a manner which is almost impossible with glazes of the majolica variety.

CLEAR MAJOLICA GLAZE.

As a further illustration of the manner in which varying conditions of work and clay may increase the complexity of a glaze, the following recipe may be cited as one used by a well-known firm after much experiment and trial. It is particularly interesting, as it has been in use continually for many years past, and the records of all the early experiments have been preserved. These show that the original glaze was the simple one already mentioned, but first one and then another ingredient has been varied until the following similar, but far more complicated, glaze is the result :—

Red lead	35 lbs.
Lynn sand	$16\frac{1}{4}$ lbs.
Cornwall stone	$12\frac{1}{2}$ lbs.
Refined borax	$6\frac{1}{4}$ lbs.
Whiting	$2\frac{1}{2}$ lbs.
Nitre	$1\frac{1}{4}$ lbs.

Compare this with the original glaze—litharge, 3 lbs. ; clay, 1 lb.; sand, 2 lbs.—and it is difficult to believe the two are really one· Yet the actual differences are but slight, as will readily be seen if the recipe of the simpler glaze be multiplied by twelve. It will then be obvious that the more complex glaze is obviously deficient in sand, though when it is remembered that Cornwall stone contains something like 75 per cent. of silica to only about 18 per cent. of alumina, it would be more correct to say that the complex glaze was more deficient in clay than in anything else, and that what has really happened is that borax, whiting, and nitre have really taken the place of the clay in the original recipe.

Will the simpler glaze do instead of the other? is a question which rises to the mind on consideration of these matters. But a little thought will show that the only answer is "No." Though so similar in composition, the changes which have been made

are important, especially as regards the melting point of the glaze, but the real difference probably lies in the differences in expansion and contraction of the two glazes. The original glaze, with its high content of clay, will require a fairly long time to "mature," or reach its highest gloss in the kiln, whilst the other will finish more readily, but will not be so durable on exposure of the glazed goods to the air, provided that both glazes were fired on the same tile. Yet the absence of the clay and the substitution for it of the other ingredients was just what was required in the particular case for which this glaze was adopted, where accuracy of colouring (necessitating a minimum of firing) was of more importance than a perfect and durable glaze.

It not infrequently happens that the glaze-maker must sacrifice some highly desirable quality in a glaze in order that he may be able to retain some other qualities which in certain instances are more important. Thus, the more complex glaze just given is clearer and more colourless than the simpler original from which it is derived, and so is more suitable for light and delicate shades, though the absence of clay from its composition, whilst adding to its clarity, detracts from its durability and general ability to resist changes of temperature.

Another typical majolica glaze is composed of :—

Red lead	146 lbs.
Lynn sand	68 lbs.
Cornwall stone	49 lbs.
Refined borax	24 lbs.
Whiting	11 lbs.
Nitre	6 lbs.

The above to be melted together and ground when cold.

It is interesting to compare this with the ones previously given. It shows the alterations nuecessary to suit one works in the Midlands.

A majolica glaze which is white and opaque and of a different type is :—

WHITE MAJOLICA GLAZE.

Felspar	25 lbs.
Borax	18 lbs.
White oxide of tin	12 lbs.
Lynn sand or flint	2 lbs.

Heat until thoroughly melted, and then add one-sixth of its weight of Flux A or B (see "Fluxes"), and grind.

It may be pointed out that the ingredient forming the opaque white in the above glaze is the oxide of tin, but this being quite infusible, must be united with the felspar and borax. This mixture, is, however, too infusible for ordinary majolica work, though it may be used as a glaze at a higher temperature, and so it must be treated with a flux or frit used in such proportions as will bring the whole within the limits of melting point and coefficient of expansion of the majolica glazes. As the various ingredients will vary somewhat in composition, it may be necessary to try mixtures of Flux A with B before a suitable white glaze is obtained. For some clays Flux A is more suitable, with others Flux B is better, and for others again a mixture of the two with the other ingredients must be employed.

HARDER GLAZES.

In the manufacture of sanitary ware and when glazes to be fired at higher temperatures are sought, a choice must be made from those rich in felspar or in Cornish stone, the necessary stability and stiffness being given by the addition of flint and any added fluxing power by the introduction of whiting or plaster.

FELSPAR GLAZE.

Felspar	12 lbs.
Flint	2 lbs.
Whiting	3 lbs.

The disadvantage of such a glaze (though it is excellent for clays firing about Cone 8) is the lack of adhesion to the articles to be glazed, and consequently such glazes have a tendency to fall off, particularly along the edges of the articles, or to curl up and run to one part of the surface.

This defect may be largely removed by adding Cornish stone or by using this material to replace some of the felspar. A substitution of this kind (together with other alterations to adapt the glaze to particular conditions) is shown in the following :—

HARD GLAZE.

Felspar	20 lbs.
Cornish stone	20 lbs.
Flint	6 lbs.
Whiting	14 lbs.

This glaze is not quite so brilliant as the previous one, and for certain purposes this is an advantage, as slight defects in the clay are not so easily seen. Like the felspar glaze just given, it has a slight tendency to curl, and some workers, therefore, prefer to use the following, which is fired about the same temperature (Cone 9), and in which a little ball clay gives greater adhesiveness to the body on which the glaze is fired.

For some purposes, a very useful material is barytes or barium sulphate, which gives great brilliance to glazes containing it, though not so good in this respect as the lead compounds. It may be added to the above-mentioned glazes in place of part

of the Cornish Stone, or it may be used with still greater success in the following :—

Felspar	51 lbs.
Cornish Stone	16 lbs.
Flint	13 lbs.
Whiting	11 lbs.
Sulphate of Barytes	9 lbs.

The only disadvantage of barytes in a glaze is that the coating must not be too thick, or the glaze becomes partly opaque, and will not clear even on repeated firings.

WHITE OPAQUE GLAZES.

The tendency of recent years is to require a glaze for bricks which shall be opaque and white in itself, and not a transparent glaze on a white body. The following recipe is in use at the present time with considerable success. It requires an easy fire, owing to its contaning lead and borax.

White Lead	43 lbs.
Cornwall Stone	20 lbs.
Flint	20 lbs.
Borax	8 lbs.
Felspar	6 lbs.
Zinc Oxide	3 lbs.

This glaze must be melted completely and ground before use.

In order to ensure that a glaze shall not craze, it is necessary to use one which has a high fusing point, and as glazes which are not heated sufficiently to completely melt all the constituents are more or less opaque, attempts have been made to use this fact in the preparation of glazes which need no under-coating of "body" in order to give a white surface to the slightly coloured clay, as do all the hard glazes just referred to.

These opaque white glazes are particularly difficult to construct, as small differences in the

purity of the materials comprising them make a serious difference to the appearance of the glaze. A white opaque glaze very popular on the Continent, and of the same composition as Seger Cone No. 5, is the following:—

Felspar	84 lbs.
Marble or Whiting	35 lbs.
Quartz or Flint	84 lbs.
China Clay	26 lbs.

This glaze requires to be fired at Seger Cone 9, or a little higher, and it is necessary that the materials shall be very finely ground, or a sufficiently brilliant result will not be obtained. It will be observed that this glaze is white without the addition of any opacity-producing agent, such as oxide of tin, so commonly used in the preparation of similar glazes, and which leads to so much trouble under certain conditions.

BRICK GLAZES.

Bricks for glazing should always be pressed so as to secure complete uniformity of size and shape. They may be glazed either before or after firing, opinions being divided as to which is the more economical course.

A "First Dip" is usually necessary in order to act as a kind of buffer between the brick and the glaze to prevent the latter from crazing. The bricks are then dipped in White Body, and finally in the Glaze, care being taken that they are dried carefully between each dipping, with the possible exception of the first dip and the body.

All excess of body and glaze should be removed from the bricks with a wire brush or a large knife.

The slips must be kept constantly stirred, and should be frequently passed through fine sieves, having 100 to 120 meshes per inch.

The firing temperature will depend on the glaze used. A hard glaze requires about Cone 7 to 9, a soft one about Cone 07.

The following glazes are each typical of its kind, but require adjusting to suit local conditions, or some of the glazes previously mentioned may be used:—

HARD GLAZE (Cone 7 to 10).

Felspar	20 lbs.
Cornish Stone	50 lbs.
Whiting	15 lbs.
Flint	15 lbs.
Water	10 galls.

If this glaze is too hard, part of the flint may be replaced by sulphate of barytes, or by felspar.

SOFT GLAZE (Cone 07).

White Lead	24 lbs.
Felspar	36 lbs.
Zinc Oxide	6 lbs.
Whiting	4 lbs.
Flint Glass	24 lbs.
Cornwall Stone	6 lbs.
Water	10 galls.

Instead of this softer glaze, the Majolica glazes may be used.

For reasons previously given, it would be useless to attempt to give any large number of recipes, as each glazer must find what temperature is most convenient, and what is the characteristic expansion and behaviour of the goods he is called upon to glaze.

It is usually wisest to start with a glaze of recognised value, such as those just referred to, and to adapt it to local conditions and circumstances. In doing this, great care and no small amount of ingenuity are required, as comparatively small differences in the proportion of certain ingredients will make all the difference to the quality of the glaze.

The chief difficulties attending the efforts to synthesise glazes according to recognised formulæ have already been shown, and the wise glazer will exercise the greatest caution before he definitely accepts an order for goods glazed with a particular mixture unless he has previously obtained perfectly satisfactory results on several dozens of tiles or bricks fired in different batches, and made up from different sets of glaze, so as to eliminate all chances of error due to special conditions in either the firing or the composition of the mixture.

BODIES.

Owing to the colour of the clay of which glazed bricks are made it is usually necessary to cover the face with a different clay, which will give the correct colour to the transparent glaze. Such covering clays or clay-mixtures are known as *bodies*, and it is seldom that a single clay can be used for this purpose.

Generally, bodies are composed of several clays united with some form of flux, such as felspar or Stone, a certain amount of flint being added to lessen the contraction of the body, and enable it to adhere to the brick or other article on which it is fired without its either cracking or peeling on account of the difference in expansion of the two.

Bodies are intermediate in character between the clay of which the goods are made and the glaze. They must be more fusible than the former, but less so than the latter, and in addition they must be of the right colour when glazed. This last is important, as if it is not necessary to change the colour of the glazed original clay it is useless to employ a body. Thus a pale blue or white brick must have a white body between the clay of the brick and the glaze, or the colour of the former

would spoil the effect it was sought to obtain, giving a greenish or brownish cast. On the other hand, it is seldom necessary to apply a body to brown glazed bricks, as the colour of the clay does not materially affect that sought in the glaze.

The formula of a body mav be calculated in a manner precisely similar to that of a glaze, but the permissable range of composition is much greater owing to the bodies being seldom completely fused. Some bodies have the same composition as glazes, except that the RO portion is composed entirely of lime (CaO) in a body, whereas it is composed of lime and potash in the glaze. Thus a typical body formula is—

$$CaO \quad 0{\cdot}5\ Al_2O_3 \quad 4\ SiO_2$$

but a body of the composition represented by the formula—

$$\left.\begin{matrix} 0{\cdot}5\ CaO \\ 0{\cdot}5\ K_2O \end{matrix}\right\} \quad 0{\cdot}3\ Al_2O_3 \quad 1{\cdot}0\ SiO_2$$

has proved successful in the case of a large firm manufacturing white glazed bricks, though its composition is most unusual.

Similarly, a very excellent body for felspar glazes has the formula—

$$0{\cdot}15\ K_2O \quad Al_2O_3 \quad 5\ SiO_2$$

and is composed of—

Felspar	20 lbs.
China clay	50 lbs.
Quartz	30 lbs.

This body is suitable for use at Cone 10.

The following are comparatively well-known bodies used for white glazed brick-making at Cones

7 to 10. They are inserted here as being of interest, and the glazer who cares to calculate the formulæ will find how closely many of them resemble each other, in spite of their apparent differences when given in recipe form, as follows :—

	A	B	C	D	E	F	G	H	J
China Clay ...	67	57	54	33	14	16	15	16	17
Ball Clay	19	19	22	21	—	—	—	—	—
Cornish Stone ...	5	10	9	21	10	12	12	11	22
Whiting	3	5	5	—	27	—	—	—	—
Plaster of Paris ...	3	7	5	2	44	—	—	8	6
Flint	3	2	5	23	5	23	19	16	17
Felspar	—	—	—	—	—	49	48	49	34
Zinc Oxide ...	—	—	—	—	—	—	6	—	4

A very typical body for use on fireclay is the following. It is generally used with the "hard glaze" (Cone 7 to 10) previously given :—

WHITE BODY.

Ball clay	9 lbs.
China clay	60 lbs.
Flint	16 lbs.
Corwall stone	10 lbs.
Whiting	5 lbs.
Water	10 galls.

It is interesting to compare the foregoing bodies with the following composition used for the manufacture of earthenware. Though termed a "body," this mixture is not used like the foregoing as a covering for the article, but is the material of which the ware is actually made.

TYPICAL EARTHENWARE BODY.

Ball clay	26 lbs.
China clay	19 lbs.
Flint	11 lbs.
Cornwall stone	8 lbs.
Felspar	8 lbs.

To prevent yellowness, prepared Cobalt stain is usually added in the proportion of 1 pint to each ton of body.

The proportions of the various ingredients may vary greatly, and the felspar is often completely omitted.

DIPS.

According to the difference in constitution between the body and the clay on which it is used, one or more intermediate bodies may be necessary. These are known as "dips." They are usually composed in part of the same clay as the bricks are made from, and the following are typical, one to three dips being used according to the nature of the material, the kind of glaze, and the "fads" of the glazer himself. It is seldom necessary to use more than one dip if it and the body are properly made, though different glazers vary greatly in the number of dips and body coats they find necessary.

	First Dip.	Second Dip.
Brick clay	36	—
Ball clay	28	48
China clay	—	32
Flint	20	12
Cornish stone	16	8

Another dip in which no brick clay is used is the following. It is typical of dips used on a very dark-coloured body, or where an unusually white

brick is desired, and is intended, for a clay with a shrinkage of 1 in. per foot. Its shrinkage may be increased by the use of more ball clay or less china clay, or it may be diminished by omitting some of the ball clay.

FIRST DIP.

Ball clay	18 lbs.
China clay	70 lbs.
Flint	5 lbs.
Cornwall stone	7 lbs.
Water	10 galls.

GLAZES FOR USE ON WHITE BODIES FOR BRICKS.

The following white glazes are used on bodies similar to the foregoing, and are fired at various temperatures. They are well-known to some of our readers, though the particular works in which they are used cannot, of course, be published.

Felspar ...	40	37	45	57	67	40	36	63	69	74	41	37	39	48	54	39	38	69	39	49
Cornish Stone	40	37	44	12	12	40	5	15	13	14	44	37	29	21	23	38	38	11	39	20
Plaster of Paris	6	8	7	5	4	8	4	—	—	4	6	5	3	—	3	—	—	—	6	—
Flint	4	4	4	—	—	4	9	10	—	—	6	5	7	14	7	11	8	7	5	13
Whiting ...	2	2	—	8	8	—	—	—	8	8	—	4	5	—	2	1	4	2	—	—
Zinc Oxide ...	8	6	—	8	9	8	—	—	10	—	—	5	7	6	14	—	6	—	5	4
Lynnsand ...	—	6	—	—	—	—	4	—	—	—	—	7	—	—	—	—	6	5	—	—
Borax	—	—	—	—	—	—	16	—	—	—	—	—	—	4	—	—	—	—	—	—
White Lead ...	—	—	—	—	—	—	11	—	—	—	—	—	—	—	7	—	—	—	—	7
China Clay ...	—	—	—	—	—	—	4	12	—	—	—	—	3	7	—	—	—	—	—	—
Tin Oxide ...	—	—	—	—	—	—	11	—	—	—	—	—	—	—	—	—	—	—	—	—
Flint Glass ...	—	—	—	—	—	—	—	—	—	—	—	—	7	—	—	11	—	6	6	7

Here again, a calculation of the formulæ will show the interested glazer how great is the resemblance between glazes used for the same purpose in different parts of the country, in spite of the enormous pains which are used to keep these compositions secret. The accompanying typical earthenware glaze may also be studied for the sake of comparison.

TYPICAL EARTHENWARE GLAZE.

Frit (melt) the following together, mixing thoroughly. Pour the melted mass into cold water, so as to break it up, dry, grind, and use, as directed, as "frit":—

Flint	66 lbs.
China clay	28 lbs.
Whiting	38 lbs.
Borax	50 lbs.
Soda crystals	20 lbs.

Grind the following together with water, and sift thoroughly through fine lawns before use:—

Above frit	60 lbs.
Flint	5 lbs.
Whiting	3 lbs.
Cornwall stone	18 lbs.
White lead	14 lbs.

One point deserves further notice; it will be seen that some of the glazes contain white lead and others flint glass; as both these substances contain lead they cause the glazes containing them to melt at lower temperatures, and to some extent they reduce their durability on exposure to weather. They are, however, useful where it is necessary to fire at rather lower temperatures than will secure the best and most durable glazes.

CHAPTER VII.

COLOURED GLAZES.

Coloured glazes are usually made by the addition of some oxide capable of producing the required colour to either glaze, or to an underlying "body," which may afterwards be covered with either a colourless or stained glaze. The precise shade produced depends on the nature of the glaze or body used, on the temperature and nature of the firing, and on the means used to spread the colouring material on the goods. To a lesser extent it is dependent on the thickness of the layer of body and glaze, and on the colour of its surroundings.

In some cases, the body may be dispensed with when coloured glazes are used, but the colour of the clay then affects that of the glaze, giving blues a greenish shade with buff clays, and all light colours a dirty brownish tinge with red-burning clays.

It will, therefore, be readily understood that the preparation of glazes of various colours is one of the most difficult pieces of work which the glazer is called upon to carry out, and the success reached depends on so many factors that experience, skill, and an endless desire "to do better" are all equally essential to success.

In addition to these qualities, coloured glazes and bodies require the exercise of great skill on the part of the chemical manufacturer, as well as the ability of the fireman, for as the slightest carelessness or mistake on the part of any one of these men will result in a different colour being produced.

A large number of metallic compounds combine with silica and with various glazes (silicates) to form coloured silicates, the composition of which is by no means fully understood, except in some of the simpler cases.

An interesting experiment on a small scale may be easily made to illustrate this point. If a piece of fine platinum wire has its end bent round so as to form a loop the size of this letter—O—and this loop be dipped into a little powdered borax and heated in the flame of a burner with the aid of a blowpipe, the borax will gradually melt to a small bead of clear, transparent glass. By repeated dippings and re-heatings a glass bead may be obtained the size of the loop.

If this hot bead be then allowed to touch a tiny particle of some metallic compound, and then re-heated it will become coloured according to the metallic compound used. Thus cobalt compounds give a blue, iron compounds a red-brown, chrome compounds a yellow or red and green colour, according to the oxidizing or reducing nature of the flame used, and the temperature to which the bead had been heated.

This simple experiment illustrates at a relatively low temperature what takes place inside the kiln when coloured glazes are being made, the chief difference being that by using other materials than borax and a great variety of colouring compounds a range of colours is obtained which is only limited by the temperature of the kiln and the materials available. Most of the colours which can be produced satisfactorily at a temperature of 1,000 deg. Cent. (majolica colours) give quite different colours (usually unpleasant ones) at 1,350 deg. Cent. (the ordinary temperature for glazed bricks), so that the number of colours which can be used at the higher temperatures is relatively small, though the searches of a number of chemists in British and foreign potteries are rapidly adding to the list of available colours.

The introduction of colouring materials adds further complications to the original simple glaze, as the infusible nature of many of the colouring matters can only be overcome by adding some material which will form a flux with them. This

will tend to form a glaze, melting at too high a temperature, and to overcome this new difficulty a further modificaion is required.

Thus the following, under certain conditions, gives an excellent

OLIVE GREEN.

Oxide of Chrome	4 lbs.
Oxide of Copper	1½ lbs.
Oxide of Cobalt	½ lb.
Litharge	9 lbs.
Flint	3 lbs.
Borax	6 lbs.

In this case, it will be noticed that although the weight of litharge is equal to that of the two following ingredients, as in the original simple lead glaze previously given, the influence of the colouring oxides is such as to seriously reduce the amount of silica (though for purity of colour flint has been substituted for sand, this makes no real difference in the composition of the glaze), and the highly infusible clay has been replaced by a still larger proportion of the easily fusible borax, which has the special power of combining with metallic oxides at comparatively low temperatures to form easily fusible glazes.

This green glaze, then, is simply the original glaze with the modifications necessary to adapt it to the inclusion of the colouring matter, though it would be difficult to recognise in the recipe just given the one from which it was constructed.

Owing to special difficulties in the refining of the oxides and other chemicals used as pigments, it is undoubtedly best for the glazer who has not had a thorough training in chemical manufacture to purchase his colours ready-made. So large a range of materials for the production of colour can now be obtained from reliable dealers in potters' materials that it is not worth while for the glazer to make his own.

These dealers will indicate more accurately than it is possible to do here the best materials suitable for any given conditions, but it must always be remembered that they are essentially sellers of materials, and that they cannot be expected to recommend, with entire certainty, colours which will be suitable for each and every case.

The warning given previously as to the necessity of testing materials purchased before employing them for regular work applies with special force to colours, as the manufacturers limit their liability strictly to replacing defective colours with an equal weight of fresh material, and the glazer who is so foolish as to save himself the small labour of tests may some day find that through lack of care he has spoiled a whole ovenful of goods by decorating them with a wrong colour, or with an improperly prepared pigment.

Coloured glazes often require rather less heat than the clear white ones. In some instances all that is required is to add a definite quantity of a single oxide (such as copper oxide) to an ordinary transparent glaze (see "Stained Glazes"), but it not infrequently happens that when the glazes are to be fired at comparatively high temperatures, the range of colours which can be produced is much smaller than when lower temperatures are used, and much greater skill is needed in order to get even results and a constancy of shade in different kilns. On the other hand, when excessively low temperatures are used, the palette also becomes restricted, though in a less degree, and other difficulties arise.

It may be taken as generally correct that a temperature between 800 and 1,000 C. is the most suitable for coloured glazes, and that at temperatures above 1,350 C. the number of colours becomes so small as to render their use confined to too narrow a range to be generally profitable, except to form relieving colours among large masses of cream or white glazed bricks.

STAINED GLAZES.

The so-called stained glazes are ordinary glazes to which a small proportion of colouring material has been added, so that on firing a coloured glaze is produced. The number of colours possible varies with the temperature used in the kiln, being like the answer to a well-known conundrum, "the higher the fewer."

Recipes for the production of stained glazes are, broadly speaking, a delusion and a snare, as the shade produced is subject to so many variations with each difference in the heating of the kiln, and in the fineness and purity of the materials used. Such recipes are only useful as rough guides as to the colouring materials used, and definite shades must be made by each glazer himself by such modification of the proportion of colouring matter as may best seem to meet his special conditions.

The combined effect of a stained glaze on a coloured under-glaze body is often very pretty, and not infrequently quite different from what would be expected. Similarly the use of a stained glaze on a white body often produces surprising results, the white background not only giving the colour a purer tone, but, by transmitting the light through the glaze, as well as the latter reflecting it from the surface, quite different shades are produced.

For delicate blue and green shades on a buff or red burning clay some form of white body or dip is almost essential, but for browns and other colours into the composition of which yellow or red enters, the use of a white body is generally a source of needless expense, trouble, and labour, as well as increasing the liability of the goods to shell or show other defects.

It need scarcely be pointed out that the simpler the glaze and the method of its application, the less liability is there to errors and defects, but this simplicity must not be carried too far, or the very troubles it is sought to avoid will be brought about.

The following are much used for coloured bricks :—

The materials should be mixed together in the form of a powder, heated in crucibles in the kiln, and afterwards ground. For use, one pound of the prepared colour may be mixed with about nine pounds of either white body or glaze, according to the shade or colour required, different effects being produced according as the body or glaze is coloured. It is seldom necessary to colour both.

BLUE (ROYAL).

Precipitated Alumina	62 lbs.
Zinc Oxide	25 lbs.
Cobalt Oxide	13 lbs.

CHESTNUT BROWN.

Brown Manganese	35 lbs.
Green Oxide of Chrome	17 lbs.
Zinc Oxide	32 lbs.
Sulphate of Barytes	16 lbs.

CELADON.

Green Oxide of Chrome	21 lbs.
Cobalt Oxide	10 lbs.
Zinc Oxide	27 lbs.
Flint	42 lbs.

GRASS GREEN.

Black Copper Oxide	7 lbs.
Green Chrome Oxide	80 lbs.
Flint	13 lbs.

ORANGE.

Iron Scales	6 lbs.
Bichromate of Potash	12 lbs.
Precip. Alumina	60 lbs.
Zinc Oxide	22 lbs.

CRIMSON.

Crimson cannot be produced at high temperatures, so that for this colour Majolica glazes must be used.

Other colours may be obtained by using Majolica glazes. (See later).

UNDER-GLAZE COLOURS.

The term "under-glaze colour" (often abbreviated to "U.G.") is used to indicate the application of the colouring material to the goods direct or to the body underlying the glaze, the latter being usually transparent and colourless.

As under-glaze colours do not, necessarily, need to be fused completely (though a partial fusion is generally desirable in order to obtain a proper development of colour), the number of pigments available is much greater than the colouring material is actuallly mixed with, and becomes part of the glaze.

Most under-glazes are mixed with a special oil known as printer's oil, and are applied by means of a simple printing press to specially prepared paper. These papers are then used as transfers, from which the colour is conveyed to the article to be decorated, as when the paper is damped on the back and pressed on to the ware the colour is retained by the article, and the paper can be removed.

When a general effect of colour is to be obtained without any special design, it is usual to mix the colouring matter with a body, or, less

frequently, to spray it on to the surface of the goods with an aerograph or similar appliance. In the latter case they must usually be mixed with some oil or other adhesive. Occasionally the pigment is mixed into a very thin cream with very weak glue and poured on hot or painted on cold, and special effects obtained in this way which are not otherwise so easily obtained.

The proportion of colouring matter to be mixed with a body depends chiefly on the effect to be produced and on the colour of the underlying material—usually one-twentieth of the weight of the body will be sufficient, and sometimes it is excessive. It is most desirable that the body should contain sufficient flux to form a semi-vitrified mass, as, otherwise, the full colour of the material will not be developed, and the process will be wasteful.

The colours for which recipes are given below are to be applied and "hardened up" if necessary by a short heating in a special kiln before applying the glaze. For some purposes they may be mixed with twenty times their weight of "body," and applied by dipping:—

WILLOW BLUE.

Prepared Cobalt Oxide ...	10 lbs.
Whiting	15 lbs.
Flint	5 lbs.

Grind together thoroughly.

DARK BLUE.

Alumina	60 lbs.
Zinc Carbonate	30 lbs.
Cobalt Oxide	3 lbs.
Red Lead	2 lbs.
Borax	1½ lbs.
Flint	½ lb.

Melt the above together in a pot kiln, and grind very fine when cold.

DARK BROWN.

Oxide of Manganese	1 lb.
Chromate of Iron	6 lbs.

Grind well together.

NOTE.—There are a number of oxides of manganese, some of which are native minerals and others artificially prepared. The particular oxide used will determine the shade of brown produced.

CRIMSON.

Oxide of Tin	3 lbs.
Whiting	2 lbs.
Lead Chromate	1 lb.
Green Chromium Oxide......	¼ lb.

Heat together in a hot part of the kiln, and grind when cold.

FRENCH GREEN.

The following materials to be well mixed and heated in crucibles which have previously been sprinkled inside with flint powder. The material must be ground before use :—

Oxide of Cobalt	5 lbs.
Oxide of Chrome	23 lbs.
Oxide of Zinc	20 lbs.
Soda Crystals	10 lbs.
Borax	20 lbs.
Flint	35 lbs.

SAGE GREEN.

Flint	5 lbs.
Soda Crystals	3 lbs.
Green Oxide of Chrome	2 lbs.

Heat in hot part of kiln, and grind when cold.

PINK.

Bichromate of Potash	1 lb.
Lead Chromate	1 lb.
Whiting	9 lbs.
Oxide of Tin	19 lbs.

Heat in hot part of kiln, and grind when cold.

YELLOW.

Crude Antimony	1 lb.
Tin Ashes (see below).........	4 lbs.
Red Lead	1 lb.

Heat to ordinary pottery glazing heat, and grind when cold.

TIN ASHES.

These may be bought ready made, or may be prepared by melting scrap lead with half its weight of grain tin in an iron ladle with frequent stirring, pouring the molten mass into water to granulate it, and heating it in an open dish in a glost oven with plenty of air. They are added to make glazes white and opaque. "Brilliant White Oxide of Tin" is sometimes substituted.

BLACK.

There is no *true* black among potters' colours, all being compounded from very dark blues and browns. The following recipe produces a "black" of excellent quality when carefully prepared from good materials. They should be carefully mixed, fired in the hottest part of the kiln, and ground when cold :—

Cobalt Oxide	6 lbs.
Nickel Oxide	2 lbs.
Iron Chromate	12 lbs.
Iron Scales	1 lb.
Tin Oxide	2 lbs.
Soda Bicarbonate	½ lb.

MAJOLICA COLOURS.

The following Majolica colours are from reliable workers in this branch of pottery. They are intended to be used on "biscuit" goods, after being mixed with about twenty times their weight of body or glaze. The goods are to be fired at temperatures ranging between 700 deg. to 1,050 deg. C. (Seger Cones 018 to 05). The colours may be varied by altering the proportions in which they are mixed with body or glaze.

LIGHT BLUE.

Majolica White (see below)...	2 lbs.
Clear Glaze (see Chap. VI.)	2 lbs. (or less)
Mazarine Blue (see below) ...	1 lb.

Grind together without previous heating.

MAZARINE BLUE.

Melt together :—

Cobalt Oxide	3 lbs.
Potass. Carbonate	5 lbs.
Flint Glass Powder	30 lbs.

When cold take :—

Above mass	25 lbs.
Clear Glaze (see Chap. VI.)	19 lbs.
Cornwall Stone	5 lbs.

Heat the whole mixture in crucibles which have been sprinkled inside with flint powder and grind for use.

BROWN.

Manganese Oxide	5 to 10 lbs.
Clear Glaze (see Chap. VI.)	100 lbs.

CRIMSON.

Crimson Under-Glaze (above)	2 lbs.
Clear Glaze (see Chap. VI.)	8 lbs.

Grind together without heating.

GREEN (BLUE GREEN).

Black Copper Oxide	10 lbs.
Sand	15 lbs.
Soda Crystals	15 lbs.
Common Salt	2 lbs.

Heat in glost kiln, and, when cold, mix with sufficient Clear Glaze (see Chap. VI.) to give the required shade and gloss; then grind. From two to three times its weight of Clear Glaze will be required.

DARK GREEN No. 1.

Black Copper Oxide	10 lbs.
Clear Glaze	100 lbs.

Grind together.

DARK GREEN No. 2.

Red Lead	7 lbs.
Flint	3 lbs.
Felspar	2 lbs.
Lime Borate	2 lbs.
Copper Oxide (Black)	11 lbs.

Heat in kiln, and, when cold, grind the mass with ten times its weight of Clear Glaze. (See Chap. VI.)

LIGHT GREEN.

Flint	5 lbs.
Whiting	3 lbs.
Fluor Spar	4 lbs.
Green Oxide of Chrome	8 lbs.

Fire in hottest part of the kiln, and when cold grind with 10 to 20 times its weight of Clear Glaze. (See Chap. VI.)

WHITE.

Felspar	25 lbs.
Borax	18 lbs.
Tin Oxide	14 lbs.
Flint or Lynn Sand	1 lb.

Melt together, and then grind with one quarter of its weight of the following mixture :—

Red Lead	2 lbs.
Borax	2 lbs.
Flint	1 lb.

ROCKINGHAM WARE.

(TEAPOT BROWN WARE.)

Teapot Brown Ware is made of a cane marl, containing a considerable amount of both iron and lime compounds. To enable the body to be fired at temperatures suitable for a durable glaze, it is usually mixed with a less fusible clay, and with a little flint or pure sand. The glaze is essentially rich in lead and Manganese, the following being a typical one :—

Litharge	100 lbs.
Cornwall Stone	15 lbs.
Red Marly Clay	6 lbs.
Manganese Oxide	10 lbs.
Red Iron Oxide	3 lbs.

Grind together before use.

The particular shade of brown obtained will depend on the quality and kind of oxides used, and on their relative proportions.

COARSE POTTERY WARE.

Coarse Pottery Ware is a term used to cover a wide range of products from a fairly pure pottery of a light cream or good white colour to the common brown ware used for stew-pots and other domestic articles. The cheaper varieties are made from a mixture of common (red-burning) clay, with china clay and flint and stone. The better ware is made from a purer clay, often without admixture, and the glaze is then produced by throwing salt into the kiln at the close of the firing.

For a better class of coarse pottery (rough stoneware) the following may be used :—

BODY.

Common Clay (preferably Marl)	40 lbs.
China Clay or Fireclay	25 lbs.
Cornwall Stone	22 lbs.
Flint	13 lbs.

GLAZE.

Felspar	40 lbs.
Flint Glass	25 lbs.
White Lead	25 lbs.
Cornwall Stone	5 lbs.
Zinc Oxide	5 lbs.

If the glaze is too hard, or not sufficiently glossy, 5 lbs. of whiting may be added.

For pans and other coarse ware a simple red clay covered with a ball clay slip and then with the simple lead-clay-sand glaze previously mentioned is generally employed. The ball clay must be adjusted to suit the red-burning clay by the addition of flint until the two both shrink to the same extent on burning.

OVER-GLAZE COLOURS.

The term, "over-glaze" (often abbreviated to "O.G.") is used to denote those colours which are applied on top of the ordinary glaze, and is chiefly used where colour effects are to be produced as cheaply as possible. As the pigment is applied after the ware has been fired, it may be of almost any composition, and thousands of small pieces of pottery are made every year in which the decoration is simply a little paint (generally mixed with varnish to make it dry glossy). Colour applied in this way, and not fixed with the aid of heat, cannot be considered as legitimate pottery decoration for anything but goods of the most ephemeral description. Somewhat more durable, yet far inferior to under-glaze work, is the orthodox O.G. decoration in which the colouring material is mixed with sufficient glaze or flux to cause it to melt, and after its application to the article, is fired at a temperature solely dependent on the colouring material used.

It is, therefore, possible to make articles with a hard glaze all over, and then to apply any coloured work that may be needed, and fire it at a temperature as low as may be desired, and far below that at which the ordinary glaze melts. Having nothing to interfere with it, over-glaze colouring naturally possesses a far wider range than is possible with under-glaze work, which has to resist the action of the molten glaze above it, and effects that are quite impossible with the latter are easy to obtain with the former. At the same time, the wearing qualities of over-glaze work are indifferent, and it is, therefore, mainly used for ornamental ware, and not for the heavier branches of glazed work, such as are used in the sanitary trades, or in brick glazing.

Over-glaze finds its chief use in these latter branches in the hiding of blemishes or defects, as it is often impossible to patch up an article, after it

has come from the kiln, with a little over-glaze colour (or white), and to re-fire it at a temperature sufficiently low to prevent any risk of damaging the article as a whole, and yet sufficiently high to render the patched portion indistinguishable except to the eye of an expert.

CHAPTER VIII.

WEIGHING OUT AND MIXING.

There is much more failure in glaze-making caused by incorrect mixing of the materials than is generally imagined, not simply because of carelessness in weighing out the various quantities, but because of ignorance or carelessness in the actual mixing. Yet a glaze or body can never give uniform and satisfactory results unless every care is taken to secure its perfect uniformity of composition.

DRY MIXING.

There are two recognised methods of mixing—the dry and the slip—and both have their special advantages. The dry method, being in some ways the better for small quantities, may be considered first.

The materials are convenientlv stored in an upper room in such a way that, after being weighed, they can be conveniently shot into the mixing pans or blungers.

According to the quantities of materials to be weighed at once, buckets or tipping waggons may be used. If the latter, they should be so designed as to pass close to the bins holding the materials.

These store bins may be of any convenient pattern, though it is desirable to have them in duplicate, so that one set may hold material freshly purchased and the other the materials in actual use. In this way a supply of new material may be obtained some time before the old is exhausted, and well tested before it is used on a large scale. A highly satisfactory method is to arrange the bins in order down opposite sides of the room, and to use

each side alternately, always emptying one set of bins completely before commencing regularly with the other.

The centre of the room may conveniently hold the scales used for the weighing, and close by is a shoot for the weighed materials when these are worked in sufficiently large quantities to make it useful.

The weight of the bucket or waggon (*i.e.*, the "tare") being known, it is a simple matter to weigh out the materials in turn, care being taken to empty the material out after each weighing in order to prevent any unexpected mixture of materials as will sooner or later occur if this precaution is not adopted.

Care must also be taken that the weights are properly arranged each time, and for this purpose it is an excellent idea to have a set of counterpoise weights cast, and then filed accurately to weight, as in this way only one weight is used instead of several for each material, and the accidental omission to place one of the weights on the scales cannot be made. Thus a glaze containing one part of litharge, two parts of stone, and three parts of flint or sand, which is to be made up into 60lb. lots of glaze, would be weighed out by means of three iron blocks weighing exactly 10, 20, and 30lbs. each. It would then be far less easy to make a mistake in the weight of any one material than when ordinary weights are used.

Incidentally, the use of these special weights prevents that great care to maintain secrecy which is often thought necessary when ordinary weights are used, as no one can ascertain the value of the special weights without actually weighing them—a difficult piece of work when ordinary weights are entirely excluded or the special weights are kept safe under lock and key.

The materials having been weighed out and the correct quantity of water added, they require to be mixed as thoroughly as possible. The manner in

which this is best carried out depends on the amount to be mixed at a single time. If the quantities are small—say, under 20 gallons—hand mixing with the aid of a wooden beater, the size of a child's cricket bat, will suffice, but for larger quantities a mechanical mixer (technically known as a "blunger") must be used.

The best kind of blunger consists of a circular iron tank, inside which revolve horizontal blades attached to a vertical spindle, and rotated by gearing outside the tank. The blades are so arranged that they continually raise the material from the bottom of the tank and break it up by forcing it through the water which the blunger contains. A close-fitting lid prevents the contents from being thrown out, and allows a high speed to be maintained in the stirrers. The material is put in at the top in the dry (ground) state, and drawn off at the bottom after it has been sufficiently well mixed.

In filling the materials into the blunger, care must be taken that the correct order is maintained, as if this is not followed the materials will not mix so rapidly.

When ball clay is used, this should be placed first in the mixer, followed immediately by the flint. The machine is then set going for a short time to break up the clay and flint, after which it is stopped, and the china clay, stone, felspar, and other ingredients added together. The machine is then re-started, and the mixing continued until complete.

Plaster of Paris is sometimes used in glazes, though it is not to be recommended. It should be mixed with water and added in the form of a thin cream, so as to prevent its setting during the mixing or after.

Some workers prefer to employ a very thin slip (weighing only about 26 ozs. per pint) in the blungers, and allow some of the water to settle out

afterwards when the slip is in the storage tanks. This is not often necessary, unless the slips are so thick (owing to their richness in plastic clay) that air bubbles cannot escape properly when they are blunged at 29 ozs. per pint, as sometimes happens with bodies.

On the whole, it is better to blunge the slip with too much water rather than with too little, as in the latter case the containing air is apt to remain in the slip in spite of repeated stirring, and to cause pinholes in the finished ware. There is generally but little difficulty in removing as much clear water as may be necessary if the slips are allowed to remain quiet for a few days, so as to allow the solid material to settle to the bottom, but they must be then stirred with extra thoroughness before any of the slip is taken out for use. In ordinary practice, it is not unusual to find that this second stirring introduces quite as much air as would be retained were the slip blunged in a somewhat thicker state. This is one of those matters which must be left to the individual workman, who will adapt himself and the density of his slips to the special conditions obtaining in his particular case.

In any case, the bodies and glazes should be made in fairly large quantities at a time, for this, as already explained, greatly reduces the risks of error, enables tests to be made of the glaze before the whole bulk is brought into use, and, above all, enables the slips to undergo that slight, but distinct, fermentation which seems to be so necessary for some classes of body, although exactly what takes place on storing is by no means clearly understood. It is, however, a well-known fact that bodies which have been stored for some time show a far less tendency to come away from the materials on which they are placed than do those which have been freshly made. This fact only applies to goods which are glazed or "bodied" by dipping; if other methods are used, the differences caused by the age of the slips are not so noticeable.

SIFTING.

The materials having been carefully weighed out, mixed with the necessary quantity of water to form a thin cream or "slip," must be passed at least once throug ha fine sieve, in order that any imperfectly ground particles may be removed. Usually, the slip is sifted several times, because this repeated straining aids in the mixing as well as in the removal of larger particles, and so assists in producing a mixture of even composition.

The size of the perforations, or meshes, of the sieves used depends on the materials employed and the articles to which the slip is to be applied. Thus for ordinary glazed bricks, and sanitary ware, a comparatively coarse sieve is sufficient, but for the finest china and earthenware work, extremely fine lawns or sieves must be employed.

For most purposes sieves with 60 to 80 meshes per linear inch are sufficiently fine, though, as already noted, lawns with 100 or even 150 meshes are sometimes required.

The careful worker will count the holes in a new sieve, as mistakes may be serious, and it is comparatively easy, with the help of a magnifying-glass, to count the meshes in a single inch of the material. Special glasses are sold for this purpose, but they are not really necessary.

It is well to note here that in this country the number of meshes in a linear or "running" inch, is commonly used to denote the "No." of the sieve, thus No. 80 has 80 holes per running inch, No. 120 has 120 holes, and so on. On the Continent, however, the holes are counted per *square centimeter*, and consequently much larger numbers are required to represent the same size of sieve. Thus a No. 60 sieve in England would be called No. 576 on the Continent, and a sieve which had 120 holes per running inch is the same as a Continental one having 2,304 holes per *square centimeter*. Care must therefore be taken, when

buying sieves, to see that they are correctly marked, on either the British or Continental system, or serious differences in the value of the glaze may ensue.

In sifting large quantities of slip, it is wise to run it direct from the blunger or mixing tub through a No. 60 sieve, so as to remove any large particles, especially of flint or glass, which may easily cut the finer sieve, and to pass it through the No. 100 or 120 sieve, only after it has passed through the other. If the blunger is rightly placed, there will be no difficulty in arranging for this double sifting before the material passes on to the cisterns, or other receptacles, where it is stored.

The cisterns are preferably built with their bottoms on the floor level, and not too deep, as they are then more easily cleaned than the partly sunk and very deep cisterns, sometimes seen in old yards. The idea that sinking the cisterns partly in the ground secures more even temperature is correct, but the disadvantages arising from imbedded tanks are greater than the advantage gained through a more constant temperature.

If the materials are obtained from reliable dealers, the proportion remaining on the sieves will be very small; if it should, at any time, be larger than usual, it should be freed from all fine particles by allowing a gentle stream of water to flow over it until the water runs through the sieve perfectly clear. This operation must be carried on away from the cisterns for holding the slip, and none of the water must be allowed to enter them.

The residue on the sieve may then be dried, weighed and examined, with a view to ascertaining its composition, and complaints made in the right quarter, so that it may be prevented in the future. Excessive residue generally implies imperfect grinding, but it may also be caused by the substitution of an inferior or improper material, and may lead to serious differences in the composition of the slip.

Sieves for slip may be either of bronze, brass or silk, but should not be of iron or steel, as these latter stain the material. Silk sieves (technically called "lawns") are more delicate, and on the whole are less suitable for ordinary use than the bronze or brass sieves, though they must be used for the most delicate colours. For most purposes, however, the brass or bronze sieves will be found to meet all requirements, especially if carefully dried after each time of using.

As there is a tendency for the heavier constituents of a glaze or slip to settle out, they should always be sifted immediately before use, and at frequent intervals in the day, if a large dipping tank is employed.

It is very important that *all* the material should be sifted, and not just a little taken out and the rest thrown away. Unless the slip is thoroughly mixed, and properly sifted, a considerable amount of flint, or heavy spar, may remain at the bottom of the vessel, and the composition and properties of the slip seriously altered.

WEIGHT PER PINT.

Before being used, a slip should always be weighed, in order to see that it is of the correct density. This is easily done by carefully counterpoising a pint measure of glass or zinc (preferably the latter) on a pair of scales, filling the measure to the mark with the slip, and again weighing it. The increase in weight will give the weight per pint. It is convenient to balance the empty measure with small shot, in a little can, and to only use weights for the liquid. This saves a troublesome subtraction sum, and makes mistakes less easy. For convenience in comparing different slips it is usual to express the weight in "ounces per pint," or "oz./pt."

Many workmen can tell, from long experience, whether a slip is of the right consistency by the

"feel," but this is a rough and ready method, and it should always be checked by ascertaining the "weight per pint" at frequent intervals, as differences in the proportion of water and solid material in the slip, will affect the appearance of the finished article.

WET MIXING.

It is often convenient, where there are a number of glazes or bodies in use which contain the same ingredients but in different proportions, to prepare slips from each ingredient separately, and then to mix these slips in the desired proportions. In certain cases, too, this method has the advantage of avoiding the accurate weighing of large quantities of materials (which is extremely troublesome), as all proportions are reckoned by volume, and not by weight.

When a glaze or body is made according to a "wet recipe," the clays, flint, felspar, and other materials, are each made into slips of definite composition by mixing them each separately with water, until they each have a definite "weight per pint," according to the materials concerned. Thus :—

Ball clay	slip	usually weighs	24	ozs.	per	pint.
China clay	,,	,, ,,	26	,,	,,	,,
Cornish stone	,,	,, ,,	32	,,	,,	,,
Felspar	,,	,, ,,	32	,,	,,	,,
Flint	,,	,, ,,	32	,,	,,	,,

though slight variations from these figures occur in actual practice, as will be seen later. These figures are known as the *standard weights* for slips of these materials.

In a "wet recipe," the directions will be take so many measures, or so many pints of each slip of standard weight, in order to make up the required glaze or body.

In practice this method of measuring is very simple, but not very clear to the beginner, because the volumes or measures of the liquids used are stated in "wet inches."

The volume of a liquid may be found by multiplying the length, width and depth of the inside of the vessel containing it, providing that this be one with vertical sides. But, for any one vessel, the length and width inside are always the same, and it is only the depth that varies with the amount of liquid in it. Consequently, if the various slips are all kept in tanks or cisterns of the same shape and size, the proportions of each slip can be accurately measured by merely withdrawing slip from each, until the depth of liquid has been lowered to the required amount. If this depth is measured in inches, the number of inches reduction of depth of the liquid in each tank, will be the proportionate volume of each liquid taken out.

Thus, if it is required to mix together eight measures of ball clay, three of china clay, and six of flint, in order to form a certain material, it is not necessary to use gallon or other measures of a similar kind. Providing that the tanks or cisterns containing the slips are all of the same size, it is only necessary to put a rod, marked in inches, into each, and withdraw slip from the first until depth of liquid is lowered eight inches, that in the second three inches, and that in the third six inches, in order to obtain a slip having each constituent in the right proportion.

The use of this method of measuring by "wet inches" is therefore very convenient, it being only necessary that the "weight per pint" of each slip should be the same as stated in the recipe, and that the tanks containing the slips should be all of the same length and width inside; their depth does not matter. It should not be used where an error of "half-an-inch" is likely to be serious.

CONVERTING "WET" RECIPES INTO "DRY."

It is often necessary to know the actual proportion of solid (dry) material in a slip, in order that certain recipes or calculations made on the dry materials may be used. This is quite easily managed, providing that the "weight per pint" of the slip, and the "specific gravity" of the materials is known.

The "specific gravity" of a material is always the same for that material, and, as great accuracy in this factor is not required, the following figures will suffice :—

SPECIFIC GRAVITY OF VARIOUS SUBSTANCES.

(Approximate.)

Ball Clay ...	... 2·5	Felspar ...	... 2·6
Barium Sulphates		Flint ...	... 2·6
Barium Carbonate	4·5	Iron Oxide (red)	... 5·2
(barytes) ...	4·5	Litharge ...	... 9·2
Borax ...	... 1·7	Red Lead ...	... 8·6
China Clay	... 2·6	Whiting ...	... 2·7
Cornish Stone	... 2·4	Zinc Oxide	... 5·6

It will be noticed that the commonest ingredients of glazes and bodies, and those used in the largest proportions, clay, felspar, flint, and stone, have all practically the same "specific gravity,"=2·6, and this materially simplifies the calculations, as will be seen presently.

The dry contents, or proportion of solid matter in a pint of slip, is equal to the excess of the pint-weight over 20 oz., multiplied by the specific gravity of the dry material (as above), and divided by the specific gravity, less one.

If, as W. Jackson has suggested, the dry contents be represented by W, the weight per pint

by P, and the specific gravity of the dry material by G, this calculation may be represented by :—

$$W = (P - 20) \frac{G}{G - 1}$$

For example, the weight of a flint slip is 32 ozs. per pint. Find how much flint it contains.

The specific gravity of flint from the above table is seen to be 2·6, so that in this case, P=32, G=2·6, and W is unknown. Hence by the above formula :—

$$W = (32 - 20) \frac{2{\cdot}6}{2{\cdot}6 - 1}$$

$$\text{or } W = 12 \times \frac{2{\cdot}6}{1{\cdot}6} = 19\tfrac{1}{2} \text{ ozs.}$$

So that each pint of the slip contains 19½ ozs. dry flint, and 12½ ozs. of water, making a total weight of 32 ozs. per pint.

In a similar way, the proportion of dry material in any slip can be readily calculated, providing that the specific gravity of the dry material is known. Further than this, as the ingredients occurring in the largest proportions in most slips have all the specific gravity of 2·6 (lead compounds, frit and barytes being the chief exceptions), the proportions of dry material in slips may be calculated by the following simple rule :—

If a simpler rule is required the following may be used :—

"*Subtract 20 from the "weight per pint" of each slip mentioned in the wet recipe, and the remainders multiplied by the numbers of "wet inches" given in the recipe will give the proportions in which the dry materials are to be mixed together.*"

Thus, a wet recipe for the body directs the glazer to mix :—

5 wet inches of Ball Clay slip	at 24	ozs.	per pint.
3 ,, ,, ,, Flint ,,	at 32	,,	,, ,,
6 ,, ,, ,, China Clay ,,	at 26	,,	,, ,,
2 ,, ,, ,, Cornish Stone ,,	at 32	,,	,, ,,

Supposing that the glazer wishes to mix only a small quantity of this body (say a couple of gallons), and has no slips at the above weights ready, his simplest plan is to work out the recipe on a "dry" basis, as follows, using the above simplified rule :—

Ball Clay ...	24 — 20 = 4 ;	4 x 5 = 20.
Flint ...	32 — 20 = 12 ;	12 x 3 = 36.
China Clay ...	26 — 20 = 6 ;	6 x 6 = 36.
Cornish Stone	32 — 20 = 12 ;	12 x 2 = 24.

Consequently the ingredients are mixed dry in the proportions 20, 36, 36, and 24 respectively, or by dividing each of these by 4 to reduce them to smaller numbers, the dry recipe corresponding, original wet one will be :—

Ball Clay	5 lbs.
Flint	9 lbs.
China Clay	9 lbs.
Cornish Stone	6 lbs.

This would make about 5 gallons of body slip so that if a smaller quantity was required, a less weight would be used in each case.

Where greater accuracy is required, the determination of the specific gravity of the materials actually used must be made, because they are never perfectly pure in actual practice, and a difference in the specific gravity will materially affect the results. For most cases, however, the calculations given above are sufficiently accurate, and are used to a considerable extent in the Potteries, though less frequently in other parts of the country. This is partly due to the different methods employed in the working of the clay, it being generally necessary for a potter to use a

mixture of clays which have been worked up in slip form and then dried, whereas the sanitary ware-and-brick-maker uses a clay which has simply been crushed and pugged, without ever becoming so liquid as a slip. Hence, potters usually work by wet recipes, and other clay workers by dry ones in which the weight, and not the volume of the materials, is the basis of calculation.

TO MAKE A SLIP OF GIVEN WEIGHT PER PINT.

It is not often that a glazer requires to convert dry recipes into wet ones, though it can be easily done, when necessary, by means of the formula just given. It is, however, often desirable to know what will be the weight per pint of a given glaze or body, or how much water should be added in order to produce a slip of a definite weight per pint from a given mixture of dry materials.

For this purpose the following formula is useful; it is simply a re-arrangement of the one previously given, and the letters have the same meaning as before:—

W = Dry contents or weight of dry material.
P = Weight per pint of slip in ounces.
G = Specific gravity of dry materials.

Then

$$P = 20 + \left(W \frac{G - 1}{G}\right)$$

Thus, to find the weight per pint of a glaze slip made from 16oz. glaze, with a specific gravity (dry) of 3·8 (the excessive specific gravity is due to the glaze containing litharge), using the above formula:—

$$P = 20 + \left(16 \frac{3{\cdot}8 - 1}{3{\cdot}8}\right)$$

or $P = 20 + 11\frac{3}{4} = 31\frac{3}{4}$ oz/pint.

In other words, 16oz. of the dry glaze, mixed with water to measure exactly one pint, would weigh $31\frac{3}{4}$oz. per pint. To find how much water

must be added, subtract the weight of dry material from the weight per pint of slip (=$15\frac{3}{4}$oz).

This shows that, mixed with an equal weight of water, this glaze would produce a slip weighing about $31\frac{1}{2}$oz. per pint.

With the ordinary materials used in bodies and glazes, it will generally be found that the addition of an equal weight of water to the dry material will produce a slip weighing about 29oz. per pint, but if much lead (either as litharge or red lead), or barium compounds, are present, the slip will weigh 30 to 32oz. per pint under the same conditions. As these are somewhat heavier slips than are usually required in practice, it is generally convenient to mix the dry materials with their own weight of water before adjusting the slips accurately to the correct weight per pint.

TO ADJUST SLIPS TO CORRECT WEIGHT PER PINT.

It is often necessary to adjust the weight of a slip so that it may be of the correct consistency for the workmen using it, for the correct weight per pint is seldom obtained at once. The usual practice is to add a little water, and after well stirring, to again weigh a portion of glaze, but this method is slow and apt to lead to mistakes. The best way is as follows :—

Subtract the weight per pint desired from the weight per pint actually found, and divide the result by the weight per pint required less 20. This will give the proportion of water to be added to the slip.

Thus, supposing a glazed slip is found to weigh 30 oz. per pint, whilst the correct strength for a certain purpose is only $28\frac{1}{2}$oz. per pint. How much water should be added?

Using the above rule, $30—28\frac{1}{2}=1\frac{1}{2}$; this, divided by $28\frac{1}{2}—20$ ($=8\frac{1}{2}$), gives $1\frac{1}{2} \div 8\frac{1}{2}$ or 3/17 water to be added. This means that for each pint of slip 3/17 pints (about $3\frac{1}{2}$oz.) water must be added, or 3 pints of water to every 17 pints of slip, or 3 gallons to every 17 gallons.

CHAPTER IX.

FINAL HINTS.

In conclusion, the glazer should remember that in purchasing a book of recipes he is only buying a very small portion of that which is necessary to the successful production of glazed goods. The skill required in the grinding and mixing—to say nothing of application—of glazes cannot be purchased, but can be obtained only as the result of brain power and experience. For any man to believe that if he can only obtain the proportions of the various materials used by a glazer in a certain works that he will at once be able to become a successful glazer himself, is sheer folly. Even if a man like this appear to have everything in his favour—experience, skill, and a knowledge of some good recipes—he may fail utterly in the attempt to produce a first-class glaze on a clay slightly different to that to which he is accustomed, unless he has the ability to adapt his compositions and methods to the new material.

The facts just mentioned show how unnecessary it is for most glazers to keep the compositions they use as secret as they do, for in most cases if the other men employed in the same works were to learn their compositions they would be unable to use them to good purpose. The only object a glazer has in keeping the recipes of the glazes he uses as a secret is in those case where his position is not very secure, and where a cheese-paring policy on the part of his employers might lead them to dismiss him and substitute a "cheaper" man if they could obtain possession of the recipes.

Such cases are not as rare as they might be, and masters who are otherwise paragons of virtue

sometimes have curious ideas on this one subject, so that glazers do well to exercise what precautions they can. At the same time, it is a matter of general experience that when an employer does adopt the foolish policy of dismissing a skilled glaze mixer in order to substitute another man less skilled at a lower wage, the work generally suffers, and the master generally loses many times the saving effected in the wages of the two men.

After all, glaze preparation is quite as much a skilled job as any other in the clay industry, and though there are many men earning wages far larger than they deserve, a really capable glazer is worth all he is ever likely to receive, for it is in his power to almost ruin his employer if he persists —either through ignorance or wilfulness—in preparing his glazes wrongly or in carelessly carrying out his work.

A book of recipes is of incalculable value to the man who recognises its limitations, and who knows how to use it; the man who regards it as a sort of mascot to lead him to fortune will find in it, as in many other talismans, an evil the power of which he little imagined. Rightly understood, it may lead a man of careful, cleanly and observant habits, with a taste for experiment and a determination that nothing shall be too much trouble, and that no amount of failures shall make him acknowledge defeat, into work of a pleasant and highly remunerative character, but to the man who exercises his ingenuity merely to steal another's secrets the "book" will prove a snare, and may eventually leave him branded as a hopeless incompetent, and in a far worse plight than if he had continued in his former employment.

The advice given by a well-known artist to a youthful enquirer as to what he mixed with his paints in order to obtain certain wonderful effects is equally applicable to glaze-making. To be a successful glazer a man must mix "brains" with his materials, for without them he must inevitably fail.

Molecular Weights arranged in Alphacetical Order of the Symbols of the most Important Elements.

Al_2O_3	Alumina	102
$Al_2O_3{\cdot}2SiO_2{\cdot}2H_2O$	"Clay"	258
$Al_2O_3{\cdot}2SiO_2$	Aluminium silicate	222
$Al_2(SO_4)_3{\cdot}18H_2O$	Aluminium sulphate	665
As_2O_3	Arsenic	198
BH_3O_3	Boric acid	62
B_2O_3	Boric oxide	70
$BaCO_3$	Barium carbonate	197
$BaCl_2 2H_2O$	Barium chloride	244
$Ba(OH)_2{\cdot}8H_2O$	Barium hydrate	315
BaO	Barium oxide (baryta)	153
$BaSO_4$	Barium sulphate (barytes)	233
CO	Carbon monoxide	28
CO_2	Carbon di-oxide	44
$CaCO_3$	Whiting, chalk, marble	100
$CaFl_2$	Fluoride of lime	78
CaO	Lime	56
$CaSO_4$	Calcium sulphate	136
$CaSO_4{\cdot}2H_2O$	Plaster of Paris	172
CoO	Cobalt oxide	74·5
Cr_2O_3	Chromium oxide (chrome)	153
CuO	Copper oxide (black)	79·5
$CuSO_4{\cdot}5H_2O$	Copper sulphate (blue)	249·5
Fe_2O_3	Red iron oxide	160
FeO	Ferrous oxide	72
$FeSO_4{\cdot}7H_2O$	Ferrous sulphate	278
K_2O	Potash	94
K_2CO_3	Potassium carbonate (dry)	138
$K_2CO_3{\cdot}2H_2O$	Cryst. potassium carbonate	174
KNO_3	Nitre, salpetre	101
K_2SO_4	Potassium sulphate	174
$K_2Cr_2O_7$	Potassium bichromate	295
$K_2O{\cdot}Al_2O_3{\cdot}6SiO_2$	"Felspar"	556
MgO	Magnesia	40
$MgCO_3$	Magnesium carbonate	84
$MgSO_4{\cdot}7H_2O$	Epsom salts	246

MnO_2	Manganese di-oxide	87
Na_2O	Soda	62
Na_2CO_3	Sodium carbonate	106
$Na_2CO_3 \cdot 10H_2O$	Washing soda	286
$NaCl$	Salt	58·5
$NaNO_3$	Sodium nitrate (Chili saltpetre)	85
$Na_2B_4O_7$	Calcined borax	202
$Na_2B_4O_7 \cdot 10H_2O$	Borax	382
$Na_2SO_4 10H_2O$	Cryst. sodium sulphate	322
NiO	Nickel oxide	75
$NiSO_4 \cdot 7H_2O$	Nickel sulphate	281
PbO	Litharge	222
Pb_3O_4	Red lead	685
PbS	Galena	238
$PbCO_3$	Lead carbonate	266
$2PbCO_3 \cdot PbH_2O_2$	White lead	775
Sb_2O_3	Antimony oxide	287
SiO_2	Silica	60
SnO_2	Tin oxide	150
$SrCO_3$	Strontium carbonate	147·5
UO_2	Uranium oxide	272
ZnO	Zinc oxide	81

Table of Atomic Weights of the Elements.

Name.	Atomic weight.	Name.	Atomic weight.
Aluminium ... Al ...	27·3	Molybdenum ...	95·6
Antimony ... Sb ...	122·0	Nickel	58·6
Arsenic	74·9	Niobium	94·0
Barium	136·8	Nitrogen	14·01
Beryllium	9·0	Osmium	198·6
Bismuth	210·0	Oxygen	15·96
Boron	11·0	Palladium	106·2
Bromine	79·75	Phosphorus ...	30·96
Cadmium	111·6	Platinum	194·7
Cæsium	133·0	Potassium	39·04
Calcium	39·9	Rhodium	104·1
Carbon	11 97	Rubidium	85·2
Chlorine	35·37	Ruthenium... ...	103 5
Cerium	141·2	Selenium	78·0
Chromium	52·4	Silicon	28·0
Cobalt	58·6	Silver	107·66
Copper	63·0	Sodium	22·96
Didymium	147·0	Strontium	87·2
Erbium	169 0	Sulphur	31·98
Fluorine	19·1	Tantallum	182·0
Gold	196·2	Tellurium	128·0
Hydrogen	1	Thallium	203·6
Indium	113·4	Thorium	231·5
Iodine	126·53	Tin	117·8
Iridium	196·7	Titanium	48
Iron	55·9	Tungsten	184·0
Lanthanum ...	139·0	Uranium	240·0
Lead	206·4	Vanadium	51·2
Lithium	7·01	Yttrium	93·0
Magnesium... ...	23·94	Zinc	64·9
Manganese... ...	54·8	Zirconium	90·0
Mercury	199·8		

Specific Gravity of Various Substances.

Material.	Sp. Gr.	Material.	Sp. Gr.
Ball Clay... ...	2·5	Hematite ore ...	5·0
Cement	2·7-3·5	Marble	2·7
Chalk	1.8-2·7	Mica	2·7-3·2
China Clay ...	2·5	Pitch	1·1
Coal	1·37	Quartz	2·5
Cobalt Oxide ...	5·6	Salt	2 1
Coke	1·5	Sandstone ...	2·3
Cornish Stone ...	2·4	Sand	1 9
Clay	1·8-2·7	Tiles and Bricks...	1·5-2·6
Glass	2·5-3·3	Wax	0·97
Granite	2·7	Wood	0·47-0·85

Water = 1.

INDEX.

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